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Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report

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ABSTRACT

Nine fire tests using five different trash fuel source packages were conducted by Sandia National Laboratories. This report presents the findings of these tests. Data reported includes heat and mass release rates, total heat and mass release, plume temperatures, and average fuel heat of combustion.

These tests were conducted as a part of the U. S. Nuclear Regulatory Commission sponsored fire safety research program. Data from these tests were intended for use in nuclear power plant probabilistic risk assessment fire analyses. The results were also used as input to a fire test program at Sandia investigating the vulnerability of electrical control cabinets to fire.

The fuel packages tested were chosen to be representative of small to moderately sized transient trash fuel sources of the type that would be found in a nuclear power plant. The highest fire intensity encountered during these tests was 145 kW. Plume temperatures did not exceed 820°C.

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Executive Summary

This report presents the findings of a series of nine trash fire characterization tests. Five different fuel packages composed of simulated small to moderate trash accumulations were burned in order to obtain data on the heat and mass release rate properties of fires in fuel packages of this type. Additional data on plume temperatures, total heat and mass releases, and heat of combustion is reported.

These tests were conducted as a part of the U. S. Nuclear Regulatory Commission (NRC) sponsored fire safety research program. The tests were conducted by members of the Adverse Environment Safety Assessment Division (6447) of Sandia National Laboratories, Albuquerque, NM.

Data on fires of this type are required as input to Probabilistic Risk Assessment fire analyses. A literature review of the subject [1] revealed that while previous efforts had investigated trash fire behavior each of these previous efforts had shortcomings of one nature or another when applied to a nuclear power plant situation. Some of these previous efforts had used fuels atypical of those one would expect to find in a nuclear power plant, while others had not collected heat and/or mass release rate information.

The fuel packages tested are described in Table 1. These fuel packages were selected based on previous test efforts, NRC input, and on the results of a survey by Wheelis of transient fuel sources reported in nuclear power plant Inspection and Enforcement (I&E) reports [2]. Wheelis' study considered 75 I&E reports covering the years 1979-1984. The study also included telephone interviews of 35 I&E inspectors. The two fuel types identified by Wheelis of primary concern to the present study were paper and trash accumulations and cleaning solvents. Paper and trash was found to be reported in quantities from a single candy bar wrapper to several overflowing 55 gallon drum waste receptacles. Typical trash accumulations were in the 30-55 gallon range. For solvents, quantities from 1 pint to more than 5 gallons were reported with quantities on the order of 1 gallon considered most typical. All of the fuel packages tested in the present study fall well within the limits considered typical in Wheelis' study.

The results of the tests presented in this report were also useful in defining the relative magnitude of ignition source fires used in the Cabinet Fire Test Program (also conducted by Division 6447 for the NRC) [3]. In the cabinet fire program it was desirable to use a "small" and "credible" ignition source for electrical cabinet fire tests in order to more closely simulate potential plant scenarios. The

results of the tests described here helped to more clearly define the terms "small" and "credible" as applied to a trash fire.

The test results are summarized in Table 2. Note that peak heat release rates never exceeded 150 kW. Typical heat release rates were in the range of 20-50 kW. These heat release rates are considered reliable as a number of gas burner calibration tests were run in order to verify the heat release rate calculation process. Fire durations were typically 30-60 minutes with later stages of the fire dominated by liquid plastic pool fires in those cases involving plastic materials.

Heat release rates during these tests were considerably lower than those in a similar test effort at Lawrence Berkeley Laboratory (LBL) [4]. These differences are attributed to the choice of both fuel material and fuel configuration used in the LBL tests.

In particular, for the wastebasket fires in the LBL study the fuel consisted of torn up plastic-coated milk cartons packed into other plastic-coated milk cartons opened at each end stacked vertically in the trash container. This configuration made the fuel appear in the form of small packed chimneys of highly flammable material. This resulted in effective maximization of the potential heat output of the fire. Tests in the present series used similarly sized and constructed wastebaskets packed with plain paper and cotton rags. This resulted in significantly less intense fires. Total heat and mass releases cannot be compared as data for the LBL tests is reported for periods of only 10-15 minutes. Fire durations for the LBL tests are not reported.

When using data of this type, one must take care to use the appropriate data set. If one is involved in making assessments of critical safety, a conservative calculation is most likely called for. In such cases, use of the LBL test results may be more appropriate than use of the results presented here. The results presented here are useful to such analyses in characterizing the degree of conservatism introduced by use of the LBL data.

The data presented here will also be helpful to other efforts in which "credible" ignition sources are desirable. For instance, some cable fire test efforts have been criticized for using unrealistically intense ignition sources where small sources may have sufficed. This was a concern in the cabinet fire program.

This data also illustrates the dramatic effects of fuel type on fire behavior. Such effects complicate attempts to define a generic trash fire and characterize trash fire behavior generally.

1.0 INTRODUCTION

This report presents the results of a series of fire tests on transient fuel source packages. The fuel packages tested were intended to represent small to moderate accumulations of combustible trash such as those which might be found in a nuclear power plant (NPP). A total of nine tests using five different fuel source packages were conducted. Table 1 provides a brief description of each of the five fuel packages.

These tests were conducted as a part of the U. S. Nuclear Regulatory Commission (NRC) sponsored fire safety research program. The primary purpose served by the results of these tests is in providing guidance on the intensity and duration of exposure source fires for use in NPP probabilistic risk assessment (PRA) fire analyses. The test results reported here were also used as input to an NRC-sponsored test effort investigating the vulnerability of electrical cabinets to fire [3].

The fuel packages tested were selected in part on the basis of previous test efforts at SNL and elsewhere, and on NRC input. Another source of guidance on fuel package selection was a study of transient fuel sources reported in nuclear power plants conducted by Wheelis [2]. Wheelis reviewed 75 Inspection and Enforcement (I&E) reports for nuclear power plants covering the years 1979-1984. Wheelis' study also included telephone surveys of 35 I&E inspectors. Two fuel source catagories identified by Wheelis are of primary interest to the present study.

The first of these catagories is paper and trash. Wheelis found that paper and trash were reported in quantities as small as a single candy wrapper to quantities as large as several overflowing 55 gallon waste receptacles. The typical size reported was on the order of 30-55 gallon sized containers. All of the fuel packages tested fall well within the size range reported for paper and trash with none of the tested fuel packages exceeding the size considered typical.

The second catagory of fuel sources identified by Wheelis of concern to the present study is cleaning solvents. Wheelis found that solvents were reported as transient fuel sources in quantities from 1 pint to more than 5 gallons. The most commonly reported quantities were on the order of 1 gallon. Test fuel packages 1 and 2 each involved the burning of one quart of acetone in conjunction with other materials one could expect to be used in routine electrical contact clean-up operations. This quantity of fuel is well within the limits defined by Wheelis and somewhat below the typical quantity defined by Wheelis.

The tests described here were considered necessary based on the findings of a review of available literature on quantitative fire characterization data as it applies to NPPs [1]. In this review it was found that while some data on the burning of trash fuel sources was available from previous efforts, each of these previous test efforts had drawbacks when applied to NPP situations.

Tests in the most complete of such efforts (at Lawrence Berkeley Laboratory (LBL) [4]) were conducted using fuel configurations and materials which could not be considered typical of NPP trash sources. The LBL tests were intended to provide guidance toward the design of a standard room fire test ignition source. The use of highly flammable plastic coated paper milk cartons in the configuration of small fuel packed chimneys in the LBL tests served to effectively maximize potential fire intensity. Thus, the resulting heat release rates can be considered a worst case for trash fuel packages of that size. The only fuel configuration of a similar size which could be expected to yield significantly higher heat release rates would be one involving large quantities of highly flammable liquids.

In the tests described here, the fuel packages utilized what were considered more typical materials and configurations. The results are useful for two reasons. For many purposes, one desires a conservative or worst case analysis. In such cases use of the LBL data would be appropriate. The present tests can help in defining the degree of conservatism introduced through use of the LBL data. Secondly, in many efforts it is desirable to use a "credible" ignition source in an attempt to deflect one source of potential criticism of the test results. Many cable fire test efforts in the past have been criticized for using unrealistically severe exposure sources. The results of the tests described here should be useful in defining the intensity of a "credible" exposure fire.

2.0 THE TEST FACILITY

The facility utilized for conduct of these tests was the Building 9830 fire test enclosure at the SNL Coyote Test Field in Albuquerque, New Mexico. Figure 1 presents schematic views of the test enclosure. The facility itself is an earth covered bunker 50 feet long, 24 feet wide, and 18 feet tall at the center. This bunker has been partitioned into two chambers, each 25 feet long. The outer chamber is used to house various instrumentation and data conditioning equipment. Test fires are placed in the inner chamber.

The inner burn chamber has a system of ducts which provide inlet ventilation air through several vents located around the perimeter of the chamber. The ventilation air is forced from the outer chamber (which is vented to the external environment) and into the burn chamber. The inlet ventilation rate for these tests was approximately 2600 CFM (1.2 m^3/sec) or the equivalent of 16 room air changes per hour.

The burn chamber operates under a slight positive pressure during tests. Combustion products and through-flow air are vented out from the burn chamber through an opening in the top center of the burn chamber. This opening is connected to an 18-inch diameter horizontal stack which houses instrumentation for analysis of the exhaust gasses.

For the purposes of this test program, a gas collection hood was positioned in the center of the burn chamber over the test fires as shown in Figure 2. The lower edge of this hood was placed 11 feet above floor level. This hood helped to channel fire products more directly to the exhaust port. This resulted in increased sensitivity to low intensity fires and reduced instrumentation response time lags caused by buildup of exhaust gasses in the upper reaches of the burn chamber.

A barrier made of 1" thick marinite panels was constructed along one edge of the hood assembly. All test fuel packages were placed on a load platform below the center of the hood such that the edge of the fuel package closest to the barrier was 12 inches away from the barrier as shown in Figure 2.

Ignition of the fuel packages was achieved through the use of an electrically ignited gas pilot light. The pilot was positioned such that a small amount of the fuel source on the top of the package was ignited (typically a scrap of paper). Once ignition was achieved the pilot was pulled out of the way and extinguished. The test fuel package was then allowed to burn to self-extinguishment.

3.0 TEST INSTRUMENTATION

A variety of instrumentation was utilized in these tests. The primary objectives of the test program were to obtain heat and mass release rate information for each of the fuel packages. Secondary objectives included assessments of plume temperature and fuel heat of combustion.

For the measurement of fuel mass loss rate each fuel package was placed on a load platform during testing. The load platform was constructed from a 3'x3' sheet of 3/8" thick carbon steel supported by three "S"-type strain gauge load cells. A 4'x4'x1" marinite panel was placed on top of the steel plate to minimize radiant heating of the steel. A metal skirt was placed around the steel plate and load cells below the marinite panel. Fresh cool air was supplied to this skirted area in order to prevent heating of the platform assembly. (The air temperature in this skirted area was monitored and in no case were temperature variations large enough to cause significant changes in load cell calibration.)

Heat release rates (HRR) were measured indirectly through use of oxygen consumption calorimetry as described by Parker [5]. The concentration of oxygen in the exhaust gas was monitored through a Beckman Gas model 755 paramagnetic oxygen analyzer. Ventilation flow rates were monitored through the use of pressure probes in both the inlet and outlet flow streams. These pressure readings were converted to velocities through the Bernoulli equation for fluid flow, and in turn to volume flow rates through the cross sectional area. (Traverses of both the inlet and exhaust ducts were conducted to insure that velocity readings were representative of average values.) Nine calibration tests were conducted using gas burners ranging from 50-175 KW in intensity. Excellent agreement was observed between calculated and theoretical heat release rates for each of these tests.

Plume temperatures were monitored through a series of K-type thermocouples placed over the center of the fuel source at heights (above the fuel base) of 18, 36, 54, 72, 84, and 144 inches. For fuel packages taller than 18", the lower level thermocouples were eliminated.

In addition, video tape and still photograph records of each test were made.

Data was logged using an HP-9216 minicomputer and an HP-3497 data logger. A total of 14 thermocouple and 10 analog channels of data was typically logged. All channels were scanned once every 15 seconds for the duration of the test (typically for about one hour). Data was stored on floppy discs and recalled later for processing on an HP-9216 computer.

4.0 TEST RESULTS

4.1 General Comments on the Data and Data Processing

The tests described here were conducted over a period of three weeks during May of 1985. Ambient temperatures at the time of the tests were typically 70-80 F. All of the tests were conducted on days during which the weather was clear and dry.

Standard test procedures used in conducting these tests included the logging of one minute of "baseline" data prior to ignition. Thus in each of the plots presented here, ignition occurs at time = 1 minute. In the case of the heat release rates which are based on analysis of gas samples taken from the exhaust stack, the data has been shifted in time in order to account for the transit time of the gas samples from the exhaust stack to the oxygen analyzer. Thus, for the heat release rate plots presented, ignition effectively occurs at time = 1 minute as in all other plots.

In calculation of heat release rates by oxygen consumption, the data processing procedures included a correction for local atmospheric pressures at the test site. This correction was necessary as the test site used for conduct of these tests is at an elevation of 6350 feet above sea level. Due to this elevation, normal atmospheric pressure is in the range of 11.7 psi as compared to 14.7 psi standard at sea level. The ratio of actual ambient pressure to standard atmospheric pressure enters the calculation as a direct multiplier to the heating value per volume of oxygen consumed.

Special consideration was also given to the fuel mass data. The load platform used in these tests was made up of a steel plate supported by three "S"-type strain gauge load cells. In order to prevent thermal damage to the load cells or distortion of calibration factors through heating of the cells an air cooling scheme was utilized. This air cooling did maintain the load cells at a constant temperature but also introduced a small amount of vibration in the load platform. This vibration manifests itself as noise in the resulting data.

In order to smooth out this noise in the data, a ninth degree polynomial curve was fit to the load platform data through application of a "least squares minimization" curve fitting technique. In the data presentation both the raw data and the curve fit are shown for each test. This curve fit was then differentiated in order to obtain smooth and continuous mass loss rate information.

In general, this curve fitting procedure worked well. On occasion, however, the fitted curve would break away from the general trend of the data either at the very start or very end of the data string. This is caused by the lack of constraint on the curve outside the bounds of the data time limits. As a result, when plotting the mass loss rate information, some curves included data during very early or very late times which were clearly not in line with actual fire behavior. In such cases this data was deleted from the plot. These deletions do not detract from the general validity of the remainder of the plots.

4.2 Fuel Package One

Fuel Package 1 (FP1) was made up of a 16" x 12" x 12" cardboard box (395 g), a large "16 oz" box of "Kimwipes" or "Assembley Wipes" (562 g) (box measured 12" x 5" x 4"), and a quart of acetone (747 g) in a polyethylene wash bottle (79 g). The cardboard box with an open top was placed on the load platform. The "Kimwipes" were opened and the first tissue pulled out so that the second tissue protruded from the box. The acetone, held in a capped wash bottle, and the "Kimwipes" were then placed upright in the box. Total weight of the fuel package was approximately 1.8 kg. The fuel package was ignited through piloted ignition of the exposed tissues. Figure 3 presents a photograph of FP1 prior to ignition. Figure 4 shows FP1 at its peak intensity during fire Test 1.

This fuel package was intended to represent cleaning materials such as might be left by maintenance personnel during routine operations. Acetone is often used as an electrical contact cleaner and would typically be held in a wash bottle, such as that used in these tests. The "Kimwipes" are a typical cleaning tissue used in a variety of applications. Two tests using this fuel package were conducted (Trash Fire Tests 1 and 2).

Following ignition of the fuel package, the fire quickly spread through the tissues and ignited the cardboard box. Melting of the wash bottle presumably allowed leakage of the acetone after approximately one minute of burning. The peak intensity of the fire (approximately 110 kW) is believed to be primarily a result of intense burning of the vertical sides of the cardboard box. Following consumption of the box sides, the fire settled into a more steady mode of burning. For times after approximately 6 minutes, the fire seemed to consume the remainder of the "Kimwipes" and the plastic bottle. Virtually all of the fuel package was consumed in each test with very small amounts of plastic and paper ash remaining after burnout.

Figure 5 shows the plume temperatures for the two tests involving FP1. Figure 6 shows the fuel mass data, and Figure 7 shows the fuel mass release rates based on the curve fits shown in Figure 6. Figure 8 shows the heat release rates calculated based on oxygen consumption.

In general, the two tests of FP1 showed good repeatability. The fire in each test followed much the same pattern of growth and development. Temperatures, mass, and heat release rates for each test are quite similar.

Peak fire intensities occurred two to three minutes after ignition. Peak temperatures ranged from 720°C to 820°C. Flame heights ranged from approximately five feet early in the tests to approximately two feet late in each test (measured from the base of the fuel package).

4.3 Fuel Package Two

Fuel Package Number 2 (FP2) was made up of a 2.5 gallon polyethylene bucket (788 g), a 16 oz box of "Kimwipes" or "Assembly Wipes" (562 g) and one quart of acetone (747 g) in a polyethylene wash bottle (79 g). Total weight of the fuel package was approximately 2.2 kg. The plastic bucket was placed on the center of the load platform. The acetone in the wash bottle and "Kimwipes" or "Assembly Wipes" were then placed standing upright in the bucket. The "Kimwipes" or "Assembly Wipes" were opened and the first tissue pulled out so that the second tissue protruded from the box as they would under normal use.

This fuel package was quite similar to FP1 except that a plastic bucket was substituted for the cardboard box. As with FP1, this fuel package is of a type which might be left by maintenance personnel during routine cleaning operations. Two fire tests, designated Tests 3 and 4, were conducted using FP2. This fuel package was also used as the ignition source for several of the cabinet fire tests conducted by SNL for the NRC. Figure 9 shows FP2 prior to ignition in Test 3. Ignition of the fuel package was achieved through ignition of the tissue paper. The fire quickly spread through the protruding tissues. This resulted in initiation of melting and ignition of the plastic bucket and wash bottle within approximately 45 seconds.

During Test 3 the acetone spilled from the bucket approximately 6 minutes after ignition. This resulted in a large flash of burning acetone. It is believed that the acetone which spilled was contained on the load platform and that most of that acetone burned within 5 seconds of the spill. This type of behavior was not observed in test 4 nor in any of the cabinet fire tests which used this ignition source.

After approximately 10 minutes of burning, the plastic bucket had melted completely. A fire composed primarily of a burning plastic pool then ensued. This mode of burning continued until fire burnout. Figure 10 shows the fuel package during this steady burning period for Test 3.

Plume temperatures for fire Tests 3 and 4 are shown in Figure 11. In general plume temperatures were relatively moderate (less than 400°C). During the acetone flashing of Test 3 peak plume temperatures reached 810°C. The fuel mass histories for Tests 3 and 4 are shown in Figure 12. Fuel mass release rates based on the curve fits presented in Figure 12 are shown in Figure 13. Heat release rates for Tests 3 and 4 are shown in Figure 14.

Note that in the mass release rate plots for test 3 the acetone spill and burning is not evident. This is a result of the curve fitting procedure which tends to smooth out rapid transients. In the raw fuel mass data for test 3 in Figure 12a one can clearly see the rapid drop in mass from approximately 1.8 kg to approximately 1.4 kg at 6 minutes. This rapid transient is not reflected in the curve fit.

Flame heights were in general 1-3 feet. This is in exception to the acetone flash in Test 3 in which flames leapt briefly to 6 feet in height.

4.4 Fuel Package Three

Fuel package 3 (FP3) was made up of a 16" x 12" x 12" cardboard box (395 g), 15 lbs of folded 12" x 16" computer paper (6.8 kg) (approximately a 3" stack) and 1-1/2 lbs of crumpled paper (680 g). The box was placed on the load platform with an open top. The folded paper was placed in the bottom of the box (approximately a 3" stack) with the crumpled paper filling the remainder of the box. The total weight of the fuel package was 7.9 kg.

This fuel package was intended to represent one such as might be found in a NPP computer or control room. Cardboard boxes of computer paper are common wherever computer hardcopy units are used. These same boxes are also often used for discarding output after use.

Two tests (5 and 6) were conducted using this fuel package. Figure 15 shows FP3 prior to ignition in Test 5. Ignition of the fuel packet was achieved through ignition of a small section of the crumpled paper. The fire spread quickly through the crumpled paper consuming both the crumpled paper and the upper sides of the box. Flames were then observed to diminish quickly with flame extinguishment occurring within 15 minutes of ignition. Figure 16 shows the residue left after flame extinguishment. Upon examination of the residue, which included nearly all of the folded paper, it was found that a deep seated smoldering fire persisted. In Test 6 the fuel was checked periodically and the smoldering was observed to persist for over 1 hour after flame extinguishment. No reignition of the fuel package into open flaming was observed.

Plume temperatures for Test 5 and 6 are shown in Figure 17. Peak temperatures were approximately 265°C. Fuel mass data is shown in Figure 18. A total of only 1.0 and 0.8 kg of mass out of a total of 7.9 kg was released in Tests 5 and 6 respectively. Fuel mass release rates based on the curve fits shown in Figure 18 are presented in Figure 19. Heat release rates for Tests 5 and 6 are presented in Figure 20.

4.5 Fuel Package Four

Fuel Package 4 (FP4) was made up of a 3 gallon (approximately 6" x 12" x 18") polyethylene wastebasket (771 g), a polyethylene liner bag (35 g), 1 lb of cotton clean room rags (455 g), and 3/4 lbs of crumpled paper (340 g). The plastic liner bag was placed in the wastebasket and pressed along the inner sides. The cotton rags and crumpled paper were then mixed evenly in the trash can. This loading resulted in a full but loosely packed wastebasket. Total weight of FP4 was approximately 1.6 kg.

This fuel package was intended to be representative of waste containers such as those which could be found in NPP computer rooms, control rooms, and security monitoring stations. This fuel package is quite similar in size and weight to one of the fuel packages tested by LBL [4]. In the present case cotton and plain paper were used as the packing material as opposed to the plastic-coated paper used in the LBL study.

Two tests were conducted using FP4 (Tests 7 and 8). Figure 21 shows FP4 prior to ignition in Test 7. Ignition of the fuel package was achieved through ignition of a scrap of the paper at the top of the fuel package. Following ignition the pilot igniter was pulled out of the fire zone from the next room.

In Test 7 when the pilot was being pulled out of the way of the fire it caught on the edge of the wastebasket causing the fuel package to fall over. Approximately 1/2 of the paper and packing material spilled from the wastebasket and it was primarily this material which actually burned during the test. When the fuel package toppled it also moved the center of the fire out from under the thermocouples used for measurement of plume temperatures. Thus, the temperatures shown in Figure 22 for Test 7 are not representative of true plume temperatures.

In Test 8 the fire developed quickly in the crumpled paper packing. This caused melting of the plastic wastebasket and eventual development of a fairly steady plastic pool fire. Open flaming in Test 8 continued steadily for approximately 65 minutes. Nearly all of the fuel material was consumed in the fire with only a small amount of plastic left following fire extinguishment.

Figure 22 presents the temperature data from Tests 7 and 8. As noted above the temperatures for Test 7 are not truly taken from within the plume and are presented here only in the interest of providing a complete permanent record of the data from these tests. Figure 23 presents the fuel mass history for Test 7 and 8. Fuel mass release rates based on the curve fits presented in Figure 23 are shown in Figure 24. Heat release rates for Test 7 and 8 are presented in Figure 25.

Flame heights for Tests 7 and 8 were generally quite low. Typical flame heights remained less that 2 feet above the base of the fuel package and 6 inches above the top of the fuel package.

The intensity of burning in this fuel package was somewhat less than that anticipated. As mentioned above, LBL tested a fuel package of similar size and weight using a different packing material and configuration [4]. In the LBL tests peak heat release rates reached nearly 70 kW or nearly three times the peak intensity of Test 8. This difference is attributed to differences in the material within the waste-basket and in the configuration of that material. These differences are discussed in more detail in Section 5.

4.6 Fuel Package Five

Fuel package 5 (FP5) was made up of a 30 gallon (approximately 24" in diameter by 36" tall) polyethylene wastebasket (3.6 kg), a plastic liner bag (35 g), 3.3 lbs of crumpled paper (1.5 kg) and 2.8 lbs of cotton clean room rags (1.3 kg). As with FP4, the crumpled paper and rags were evenly mixed in the wastebasket to result in a full, but loosely packed, condition.

This fuel package was intended to represent larger industrial waste containers such as those used in a variety of applications including use in most NPP areas. A variety of materials including wood, cardboard, oily rags, paper, and plastics could have been used as the packing material. The choice of paper and cotton rags was made in order that the results might be more directly comparable to those for FP4. FP5 is also similar in size and weight to one of the fuel packages tested in the LBL test series [4].

One test was conducted using FP5 as the fuel source (Test 9). Figure 25 shows FP5 prior to ignition. Ignition was achieved through piloted ignition of a piece of paper on the top of the fuel package. The fire developed quickly in the packing material. Melting of the wastebasket was evident approximately 2 minutes after ignition. Within 15 minutes of ignition, the wastebasket had melted away almost entirely leaving a pile of burning paper, cotton, and plastic approximately 1/2 the original height of the fuel package. Shortly thereafter, this pile of burning material toppled resulting in a surge in fire intensity. As the packing material burned away a liquid plastic pool fire became the dominant mode of burning. This pool fire continued to burn for an additional 40 minutes flaring up to high intensities twice during that period. Following fire burn out approximately 1.1 kg of residue, mostly plastic, was left.

Plume temperatures for Test 9 are shown in Figure 26. Peak temperatures measured reached 360°C. The fuel mass data is shown in Figure 27 with the mass release rate information shown in Figure 28. The heat release rate for Test 9 is shown in Figure 29. The peak heat release rate for this fuel package was 113 kW. Flame heights for this test were in general 3-4 feet above the base of the fuel package with occasional flame heights of 5-6 feet during peak intensities which lasted approximately 1 minute on each of 3 occasions.

As mentioned above, this fuel package was similar in size and weight to one tested by LBL [4]. In the LBL test, the peak fire intensity was over 600 kW, or more than 5 times that seen in Test 9. In the LBL test, this peak intensity was reached within 3 minutes of ignition. These differences in fire behavior are attributed to the differences in fuel packing material and configuration. The rapid intense development of the LBL test fire can only be attributed to development of the fire within the highly flammable plastic-coated paper used to fill the wastebasket. These differences are discussed more fully in Section 5.

5.0 SUMMARY OF TEST RESULTS

The results of this series of 9 transient fuel fire tests are summarized in Table 2. This table provides the peak temperatures, heat release rates, and mass release rates for each test. The table also gives the total amount of heat released and the total amount of the fuel mass consumed. The final column presents the ratio of total heat to total mass release. This value is an estimate of the average effective heat of combustion for the fuel materials.

In general, the fires in this test effort were much less intense than those of previous efforts by LBL [4]. Peak temperatures ranged from 150°C to 920°C. Peak heat release rates ranged from 12 to 145 kW with typical heat release rates in the range from 20 to 100 kW. These heat release rates are considered reliable as a number of gas burner calibration tests were conducted in order to validate the heat release calculation process. Burn durations ranged from 15 to 65 minutes with typical durations from 30 to 60 minutes.

FP4 (Tests 7 and 8) and FP5 (Test 9) can be compared directly to similarly sized wastebasket fuel sources tested by LBL [4]. In the LBL test series, a 6.6 liter (1.75 gal) plastic wastebasket resulted in peak heat release rates of approximately 70 kW. In fire Tests 7 and 8, a larger 11 liter (3 gal) wastebasket resulted in peak fire intensities of only 24 kW. Similarly in the LBL test series, a 121 liter (32 gal) plastic wastebasket, resulted in peak fire intensities of over 600 kW. In fire Test 9, a similar sized (30 gal) plastic wastebasket resulted in peak fire intensities of 113 kW.

These differences in fire intensity for similarly sized wastebasket fires are directly attributable to the differences in the material chosen to fill the wastebaskets and the configuration of those materials within the wastebasket. In the present test series, a uniform mixture of crumpled paper and cotton rags were used. In the LBL tests .98 liter (1 qt) plastic coated cardboard milk cartons were used. The milk cartons were placed such that "half of the cartons are opened to form open tubes and are placed upright in the wastebasket. The remaining cartons are torn into pieces, measuring approximately 50-75 mm (2-3 in) square. These pieces are then placed within the tubes formed by the upright cartons." The result of this configuration is a set of small fuel loaded chimneys of highly flammable material. This has the effect of maximizing potential heat output and fire growth rate.

Further evidence that these differences in fire intensity are due to the materials within the wastebasket is available from the results on the larger wastebasket. In Test 9 of the present series the peak in fire intensity (113 kW) occurred approximately 30 minutes after ignition. This peak was attributed primarily to the burning of the molten plastic from the wastebasket itself. In the LBL test involving a similar wastebasket, the fire reached over 600 kW in 3 minutes. This quick rise time clearly indicates combustion of the packing materials is the primary source of heat release.

In using data of the type described here, one must clearly define their objectives and needs. If one is making a calculation which is intended to be "conservative" (ie, worst case fires) then use of the LBL data would be appropriate. The LBL tests can be considered as representative of a worst case ignition/exposure fire source for the size of fuel packages tested. The LBL tests appear to indicate fire intensities on the order of 3 to 5 times as intense as those in the present test series. If the user's goal is to provide a "realistic" or more "credible" ignition/exposure fire source then the present data set is more appropriate for providing guidance on the intensity of such fuel sources.

One must recognize that these tests have clearly demonstrated the dependence of fire development on the fuel material and configuration. Due to the variety of materials and configurations in which trash and other transient fuels can be found, one must exercise extreme caution in extrapolating the present data and that from the LBL tests to a particular situation.

It is also interesting to note that the LBL tests report data for only 10 minutes. In the present test series, fire durations were from 15-65 minutes. One should also recognize that the apparent fire durations for the LBL tests may underestimate actual fire durations. Most of the test fires reported by LBL appeared to be burning quite intensely at the end of the data reporting period.

The purpose of the LBL test series was to provide guidance in the definition of a standard room fire test ignition source. As a result of the LBL test series, an ignition source using a gas burner with an intensity of approximately 300 kW was recommended. This burner clearly encompasses the present tests with regards to fire intensity. Duration of this recommended ignition source is not addressed in the LBL report. In order to encompass the current test series in time durations of up to 60 minutes would be required in the absence of any credit being taken for fire suppression efforts.

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2. Wheelis, W. T., "Transient Conbustible Fuel Sources Found at Nuclear Power Plants" A letter report to the USNRC, Sandia National Laboratories, 1984.

3. Chavez, J. M., "An Experimental Investigation of Internally Ingited Fires in Nuclear Power Plant Control Cabinets; Part 1: Cabinet Effects Tests," Sandia National Laboratories, SAND86-0336, 1986.

4. Von Volkenburg, D. R., et al, "Towards a Standard Ignition Source," LBL-8306, Lawrence Berkeley Laboratory, October 1978.

5. Parker, W. J., "Calculation of the Heat Release Rate by Oxygen Consumption for Various Applications," NBSIR 81-2427-1, U.S. Department of Commerce, National Bureau of Standards, March 1982.

TABLE 1: DESCRIPTION OF FUEL PACKAGES TESTED

Fuel Package 1:

12"x16"x12" cardboard box (395 g)
"16 oz" box of "Kimwipes" (562 g)
1 qt of acetone (747 g)
in a polyethylene wash bottle (79 g)

Fuel Package 2:

2.5 gal polyethylene bucket (788 g)
"16 oz" box of "Kimwipes" (562 g)
1 qt of acetone (747 g)
in a polyethylene wash bottle (79 g)

Fuel Package 3:

12"x16"x12" cardboard box (395 g)
15 lbs of folded 12"x16" computer paper
(3 inch stack) (6.8 kg)
1-1/2 lbs of crumpled paper (680 g)

Fuel Package 4:

5 gal polyethylene trash can (~6"x12"x18") (771 g)
polyethylene liner (35 g)
1 lb of cotton clean room rags (455 g)
3/4 lbs of crumpled paper (340 g)

Fuel Package 5:

30 gal polyethylene trash can (3.6 kg)
polyethylene liner (35 g)
3.3 lbs. of crumpled paper (1.5 kg)
2.8 lbs. of cotton clean room rags (1.3 kg)

TABLE 2: SUMMARY OF TRASH FIRE TEST RESULTS

Source Fuel Package	Test #	Peak Plume Temperature (C)	Peak HRR* (kW)	Peak MRR** (g/s)	Total Heat Release (MJ)	Total Mass Release (kg)	Effective Average Heat of Combustion (kJ/g)
FP1	1	818	97	4.2	48	1.8	27
	2	720	109	3.9	37	1.8	21
FP2	3	810	145	2.0	75	2.4	31
	4	413	34	1.3	49	1.7	29
FP3	5	260	26	2.4	13	1.0	13
	6	265	21	1.9	10	0.8	12
FP4	7	---	12	0.9	25	0.8	31
	8	155	24	0.8	56	1.6	35
FP5	9	360	113	2.4	202	5.5	37

* Heat Release Rate
** Mass Release Rate

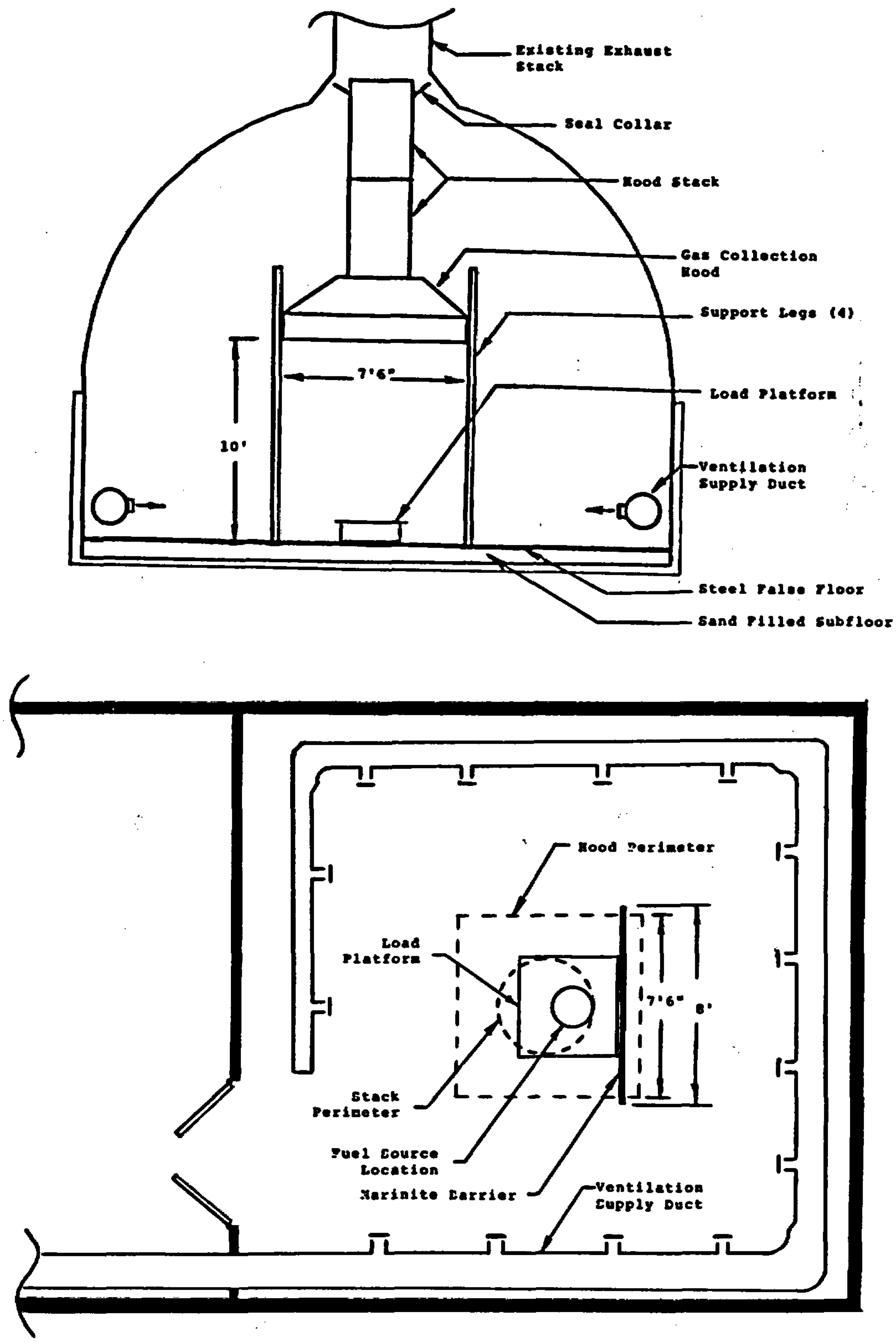


Figure 2 Exhaust gas collection hood and fuel placement used for trash fire tests

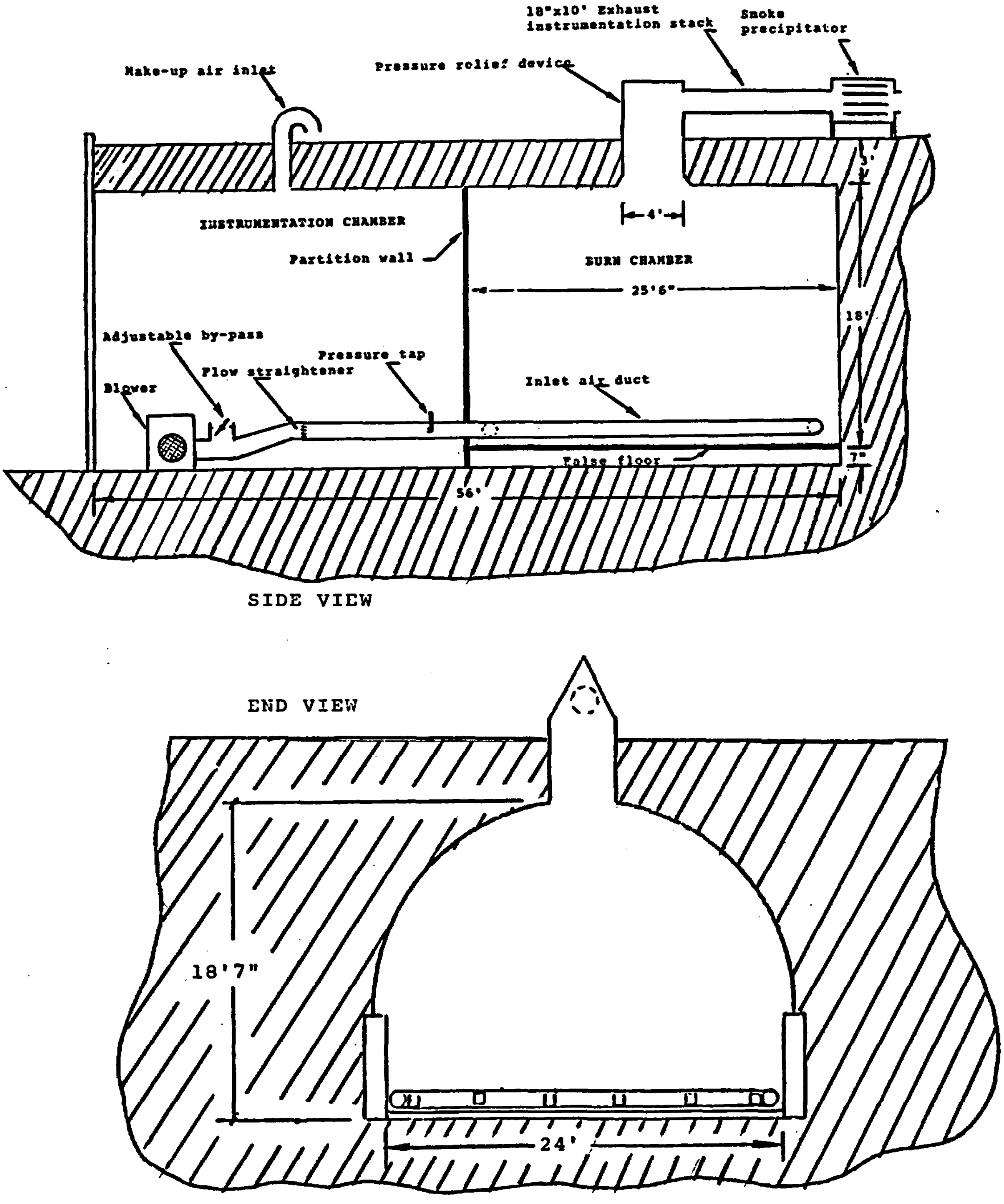


Figure 1 Schematic view of fire test facility

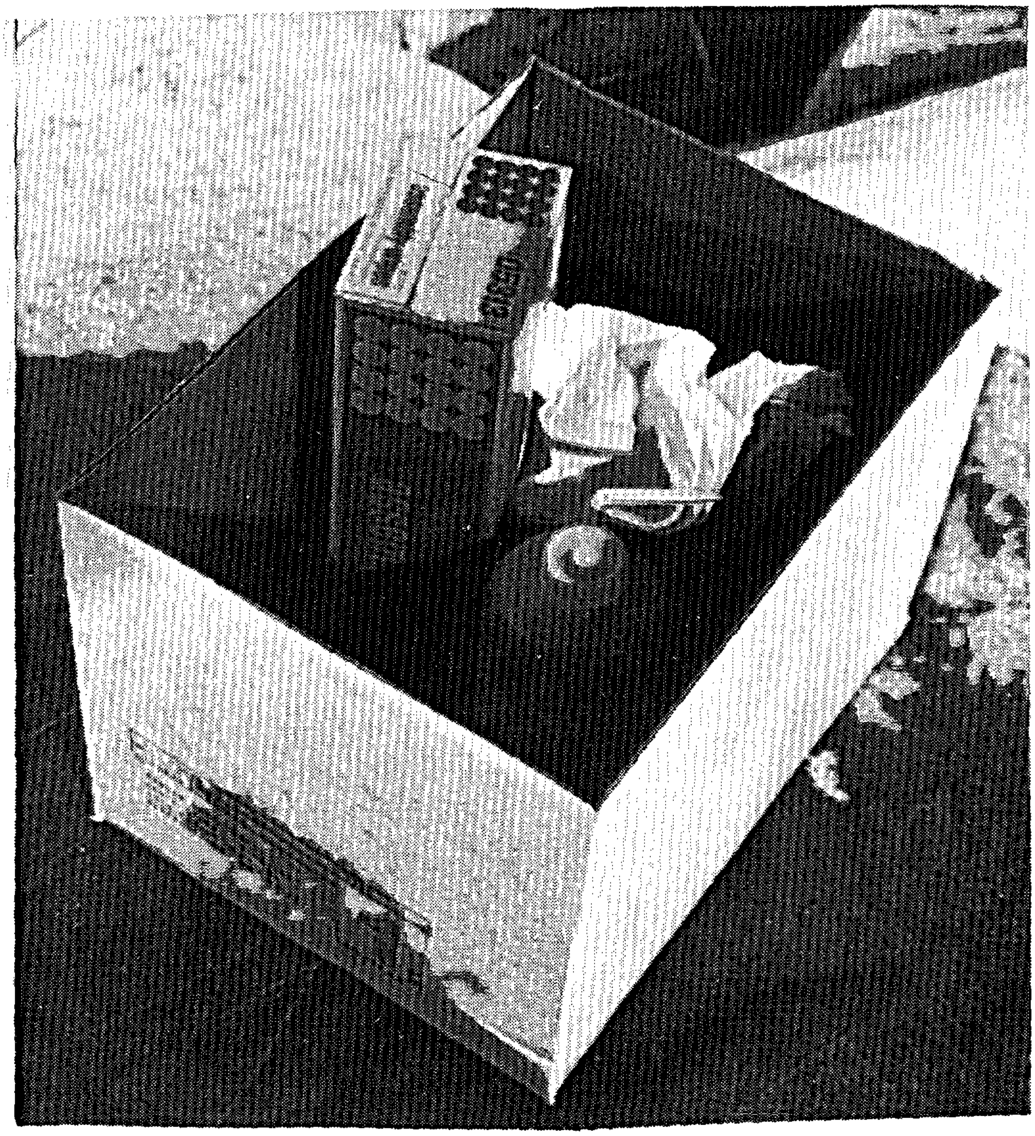


Figure 3 Photograph of FP1 Prior to Ignition

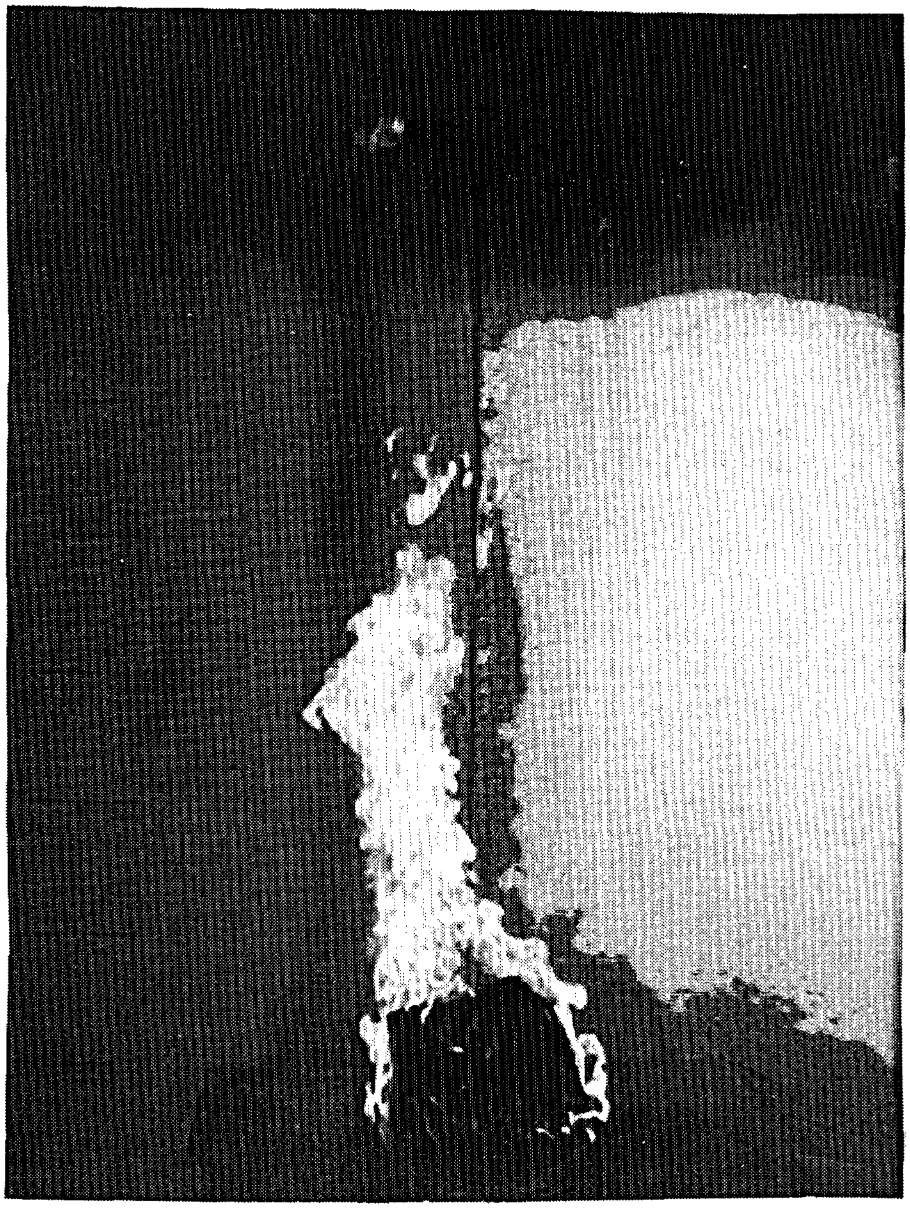


Figure 4 Photograph of FP1 at Typical Peak Intensity

Figure 5a:
Plume Temperatures for Trash Fire Test 1

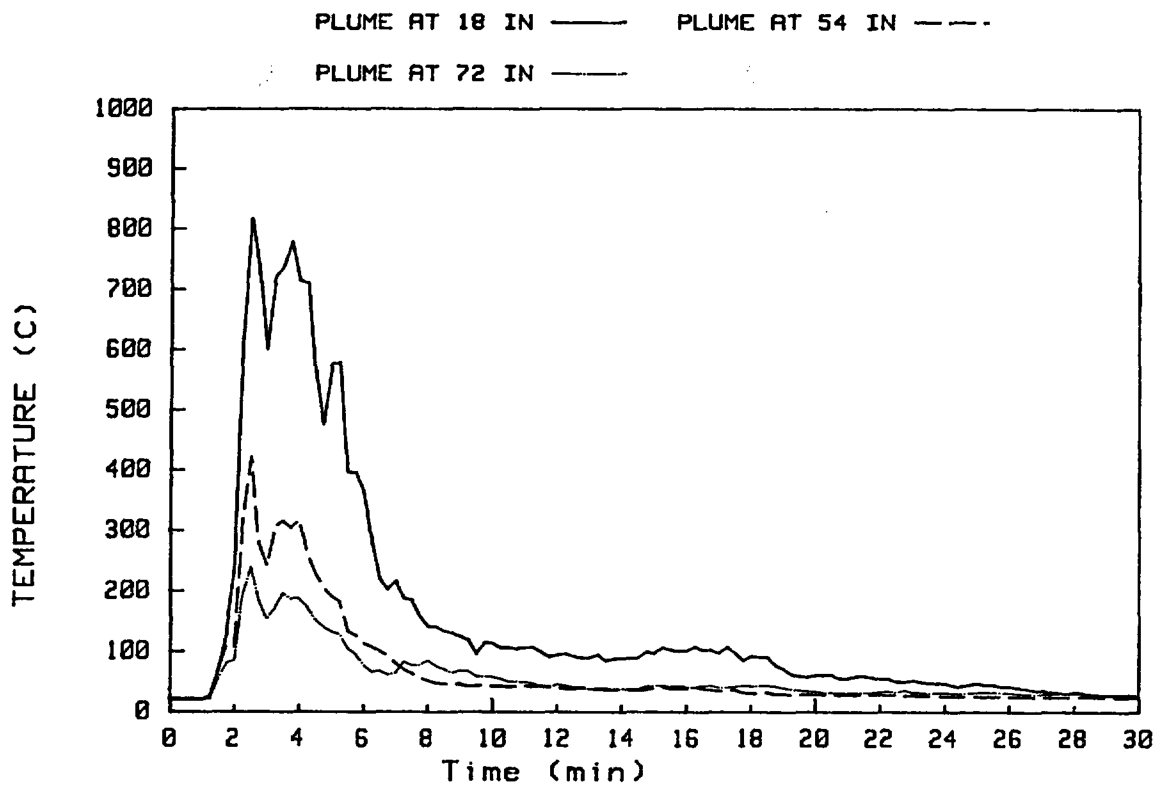


Figure 5b.
Plume Temperatures for Trash Fire Test 2

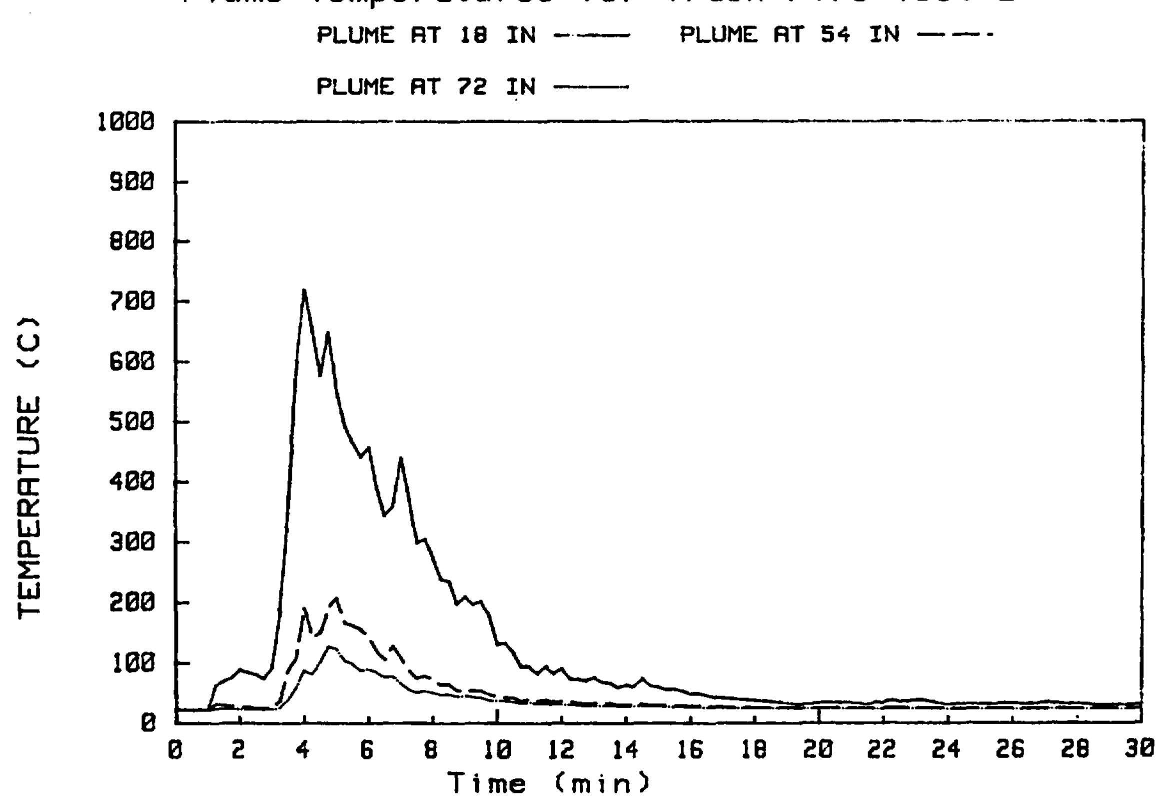


Figure 6a:
Fuel Mass for Trash Fire Test 1

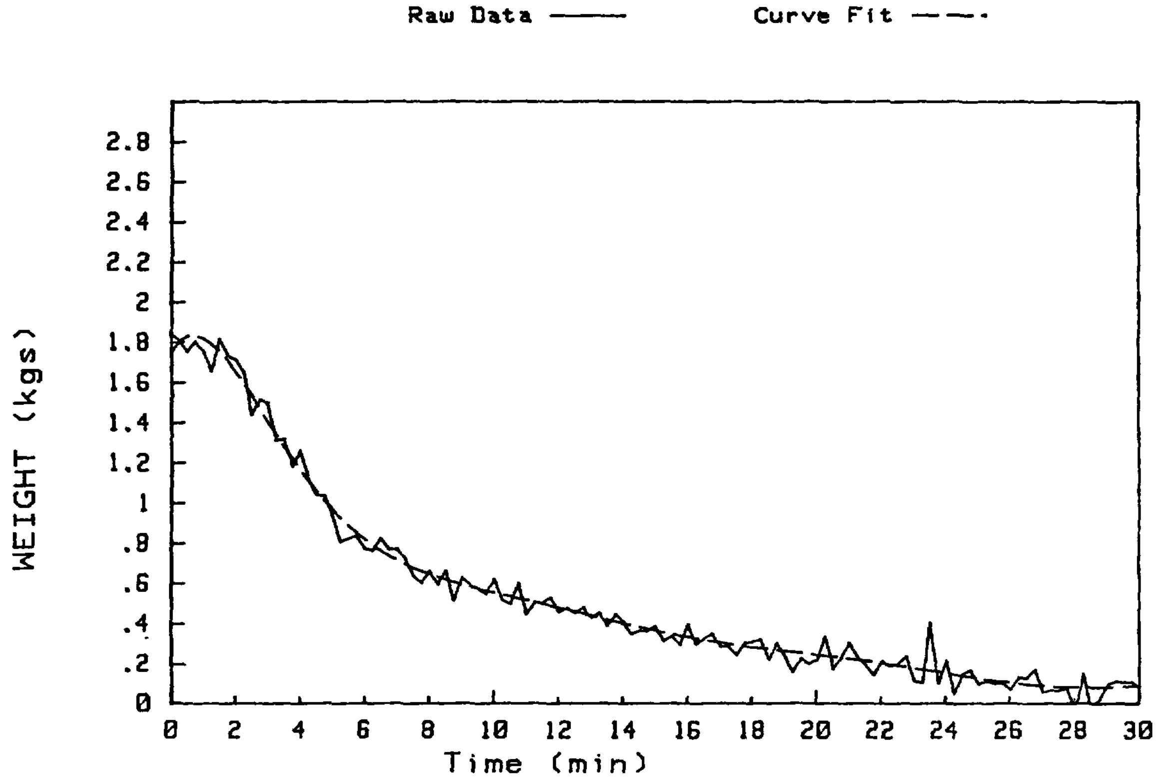


Figure 6b:
Fuel Mass for Trash Fire Test 2

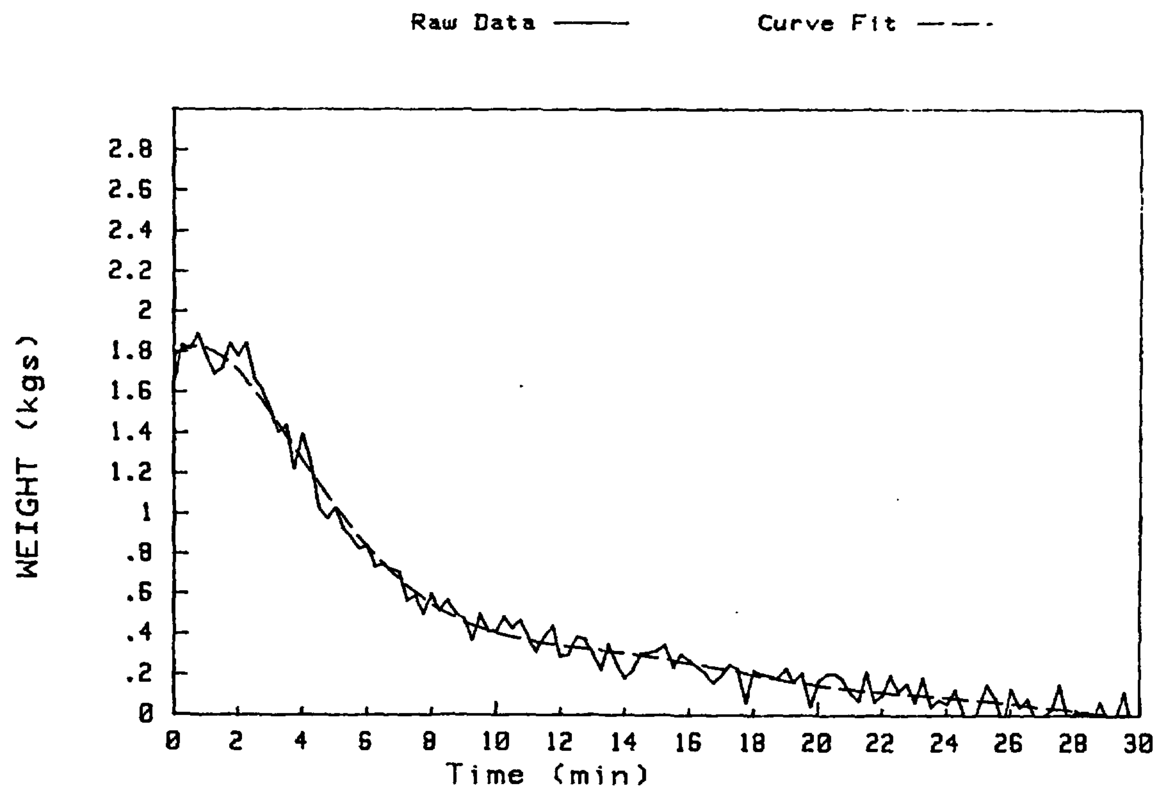


Figure 7a:
Fuel Mass Release Rate for Trash Fire Test 1

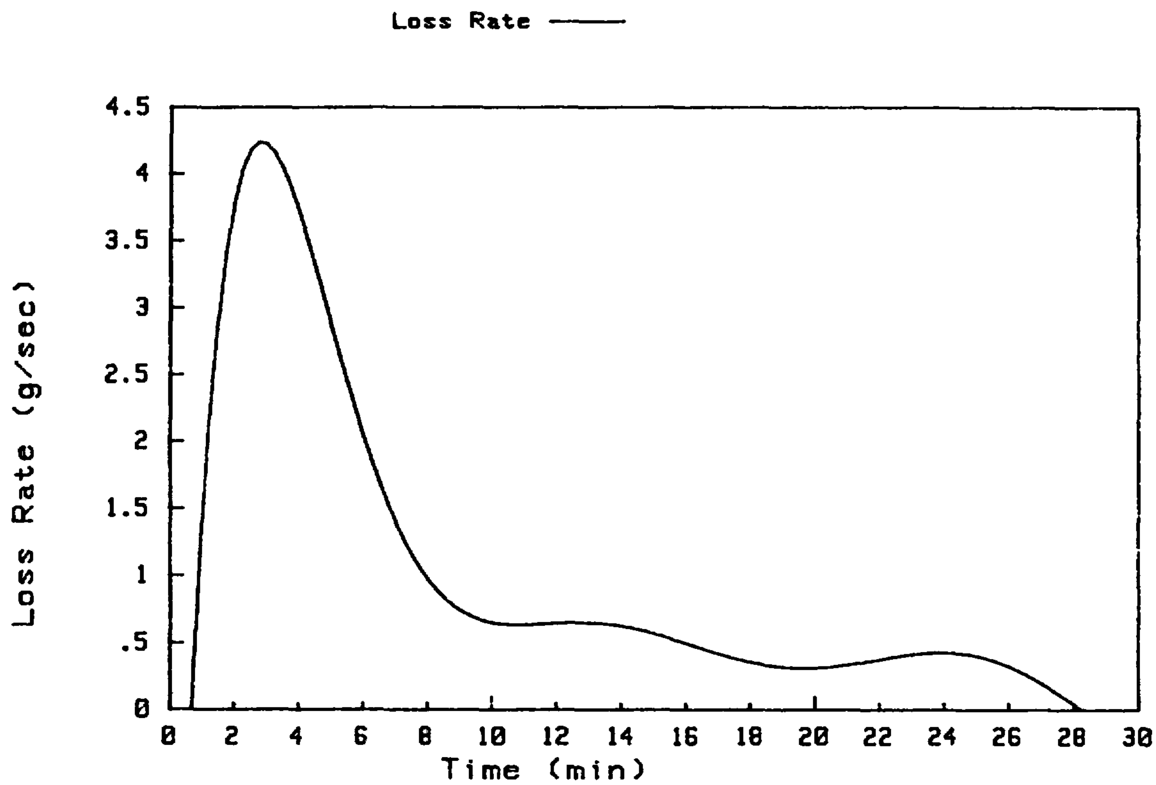


Figure 7b:
Fuel Mass Release Rate for Trash Fire Test 2

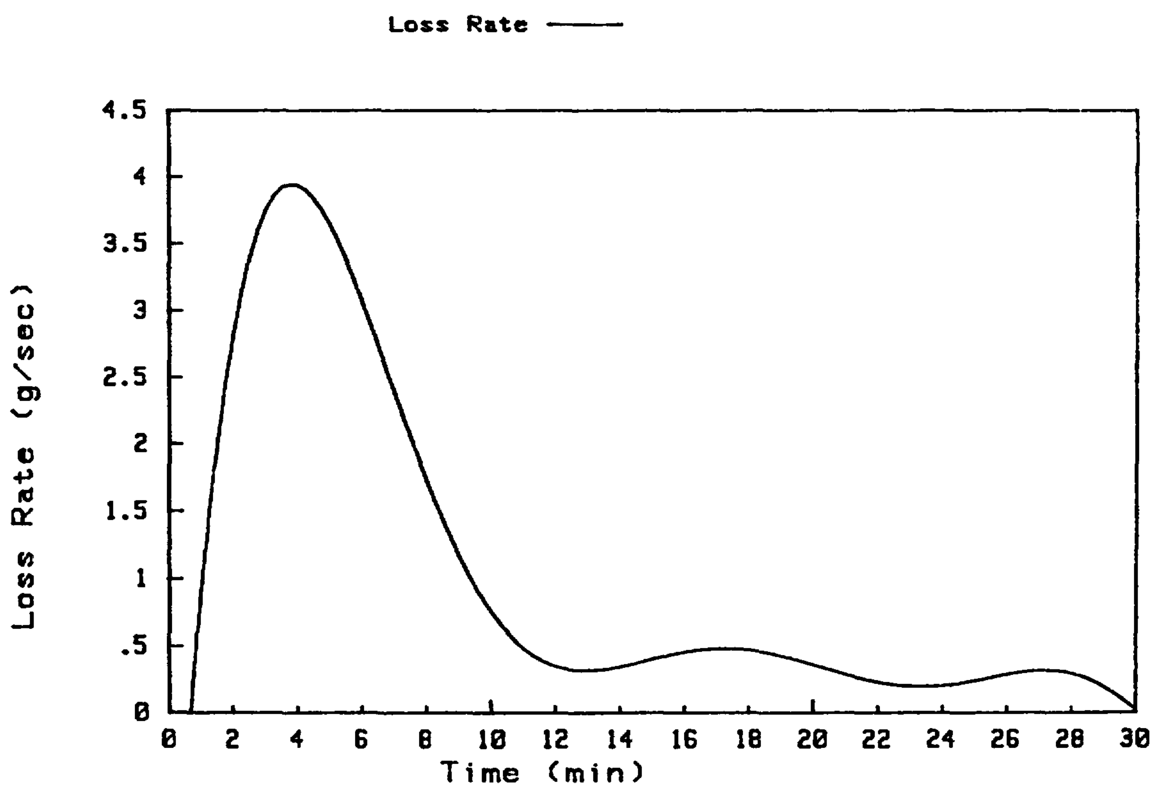


Figure 8a:
Heat Release Rate for Trash Fire Test 1

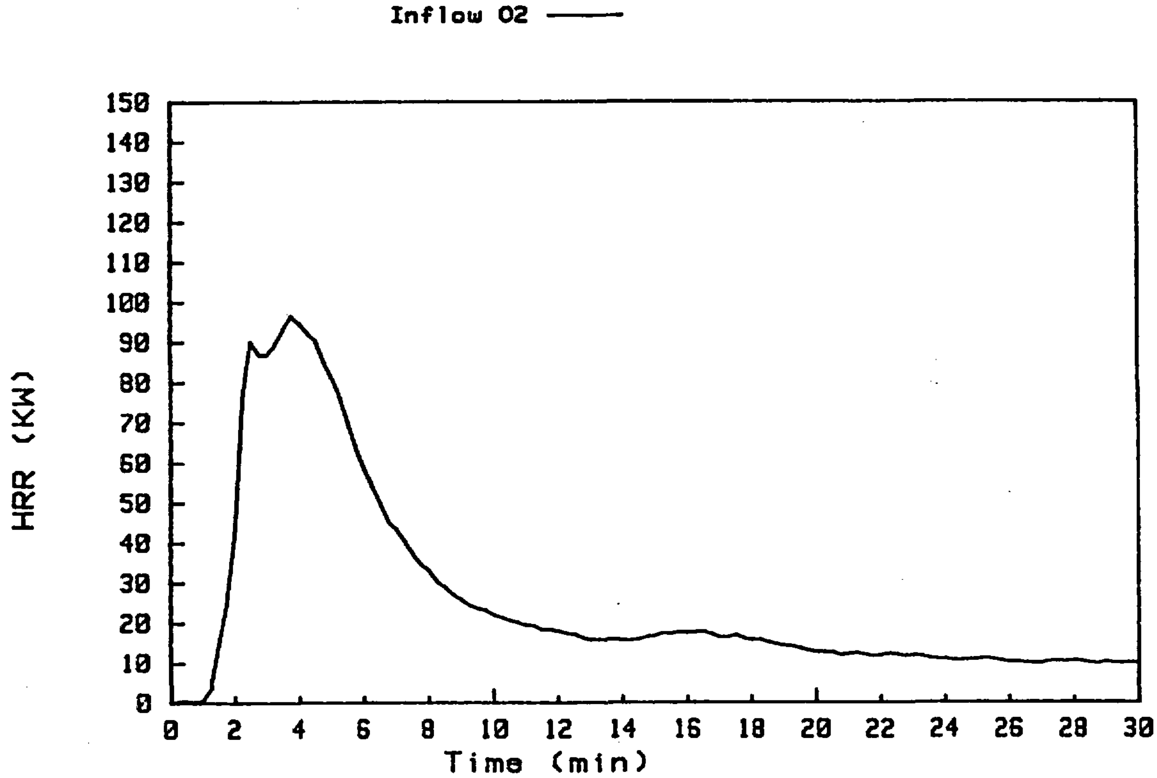
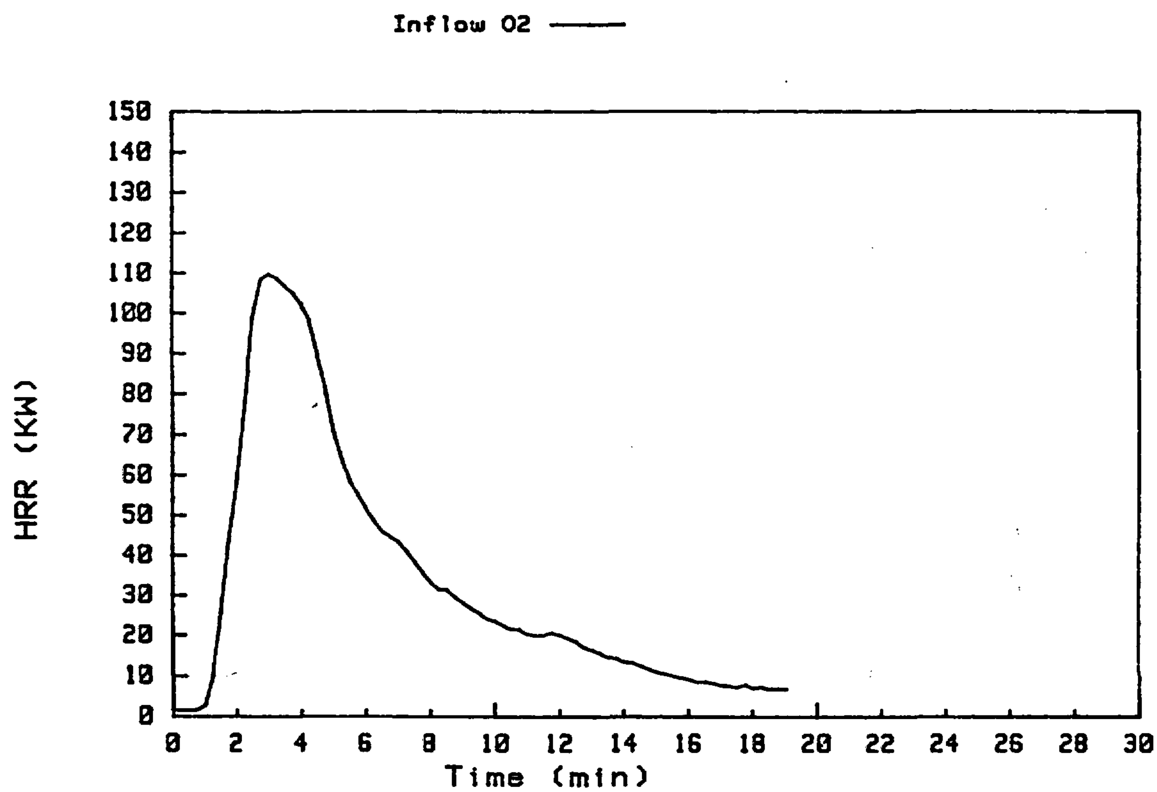


Figure 8b:
Heat Release Rate for Trash Fire Test 2



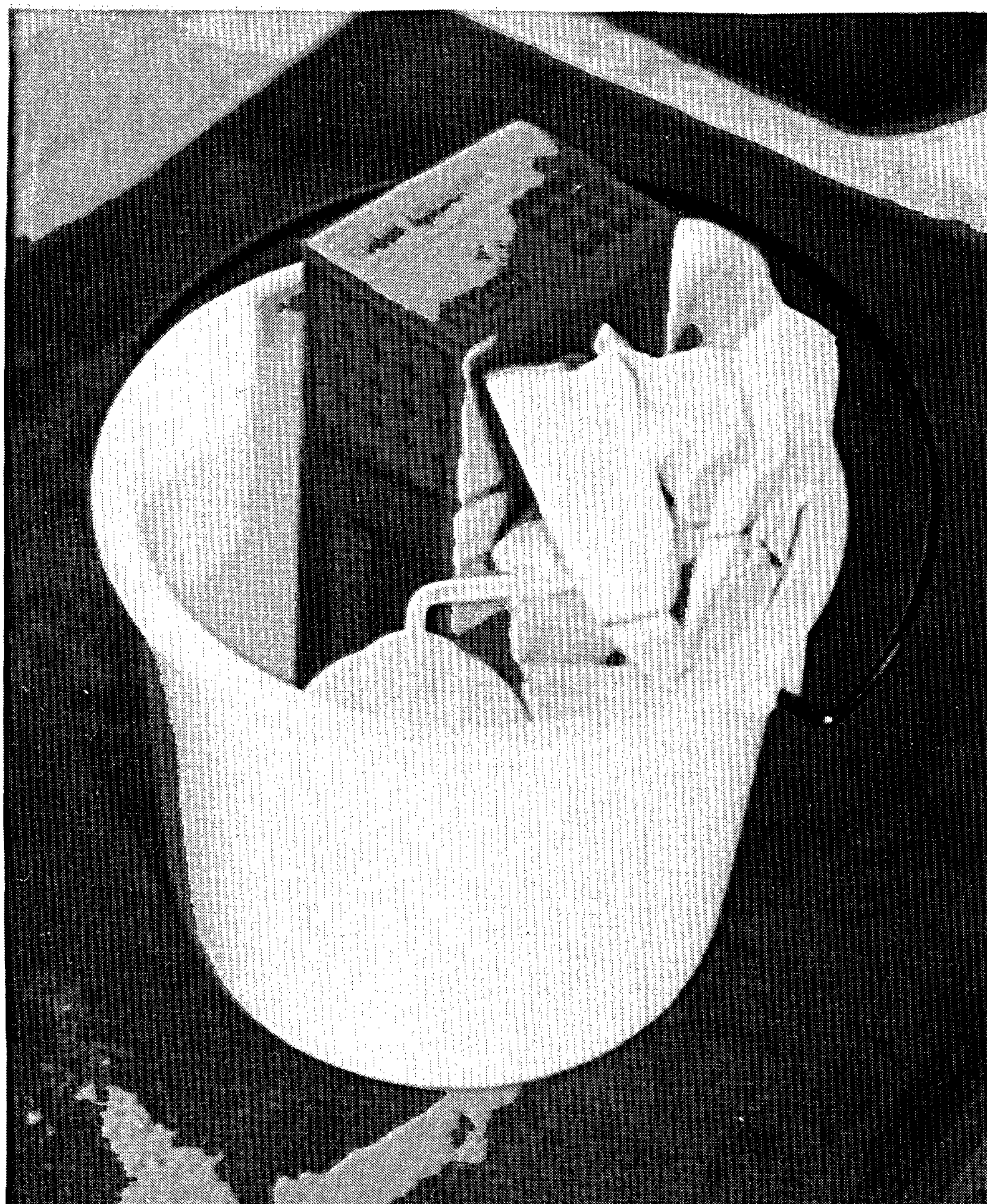


Figure 9 Photograph of FP2 Prior to Ignition

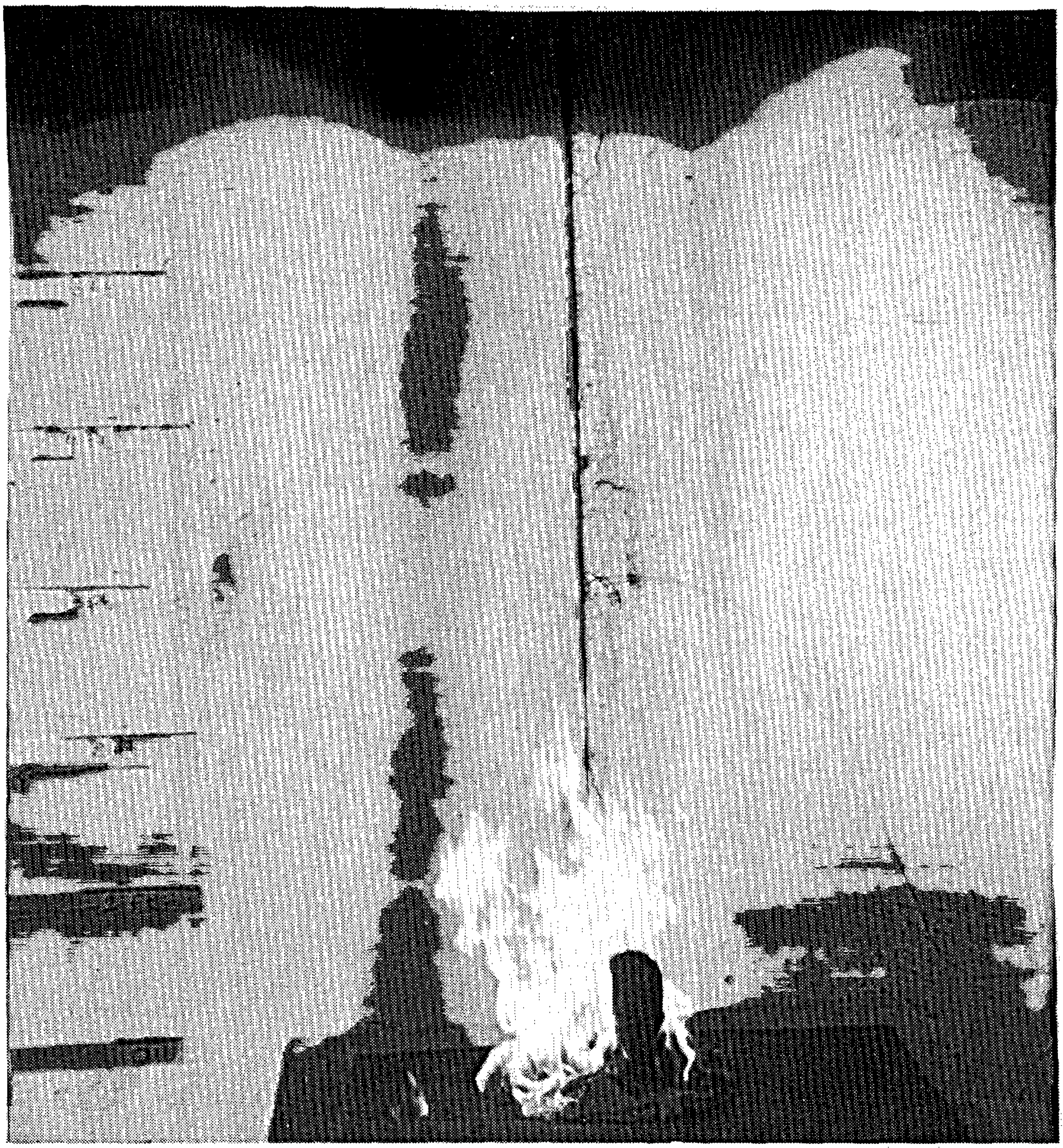


Figure 10 Photograph of FP2 at Typical Peak Intensity

Figure 11a:

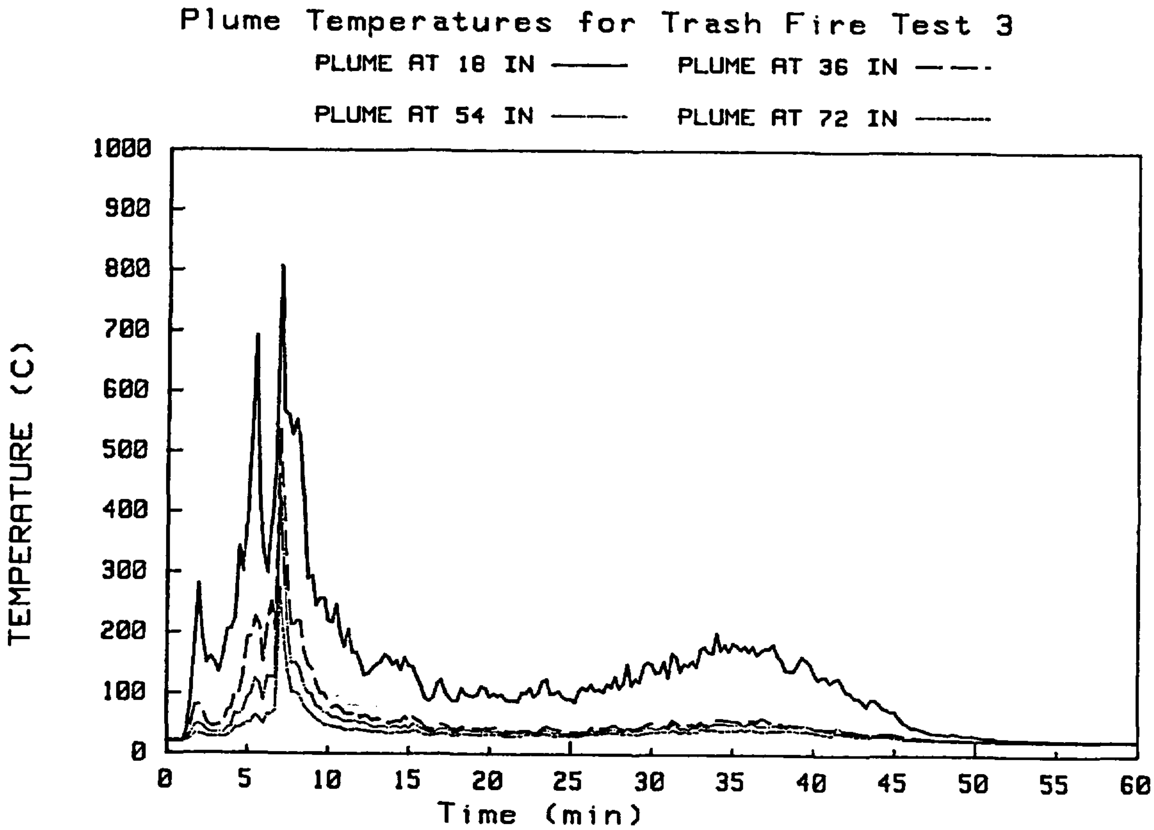


Figure 11b:

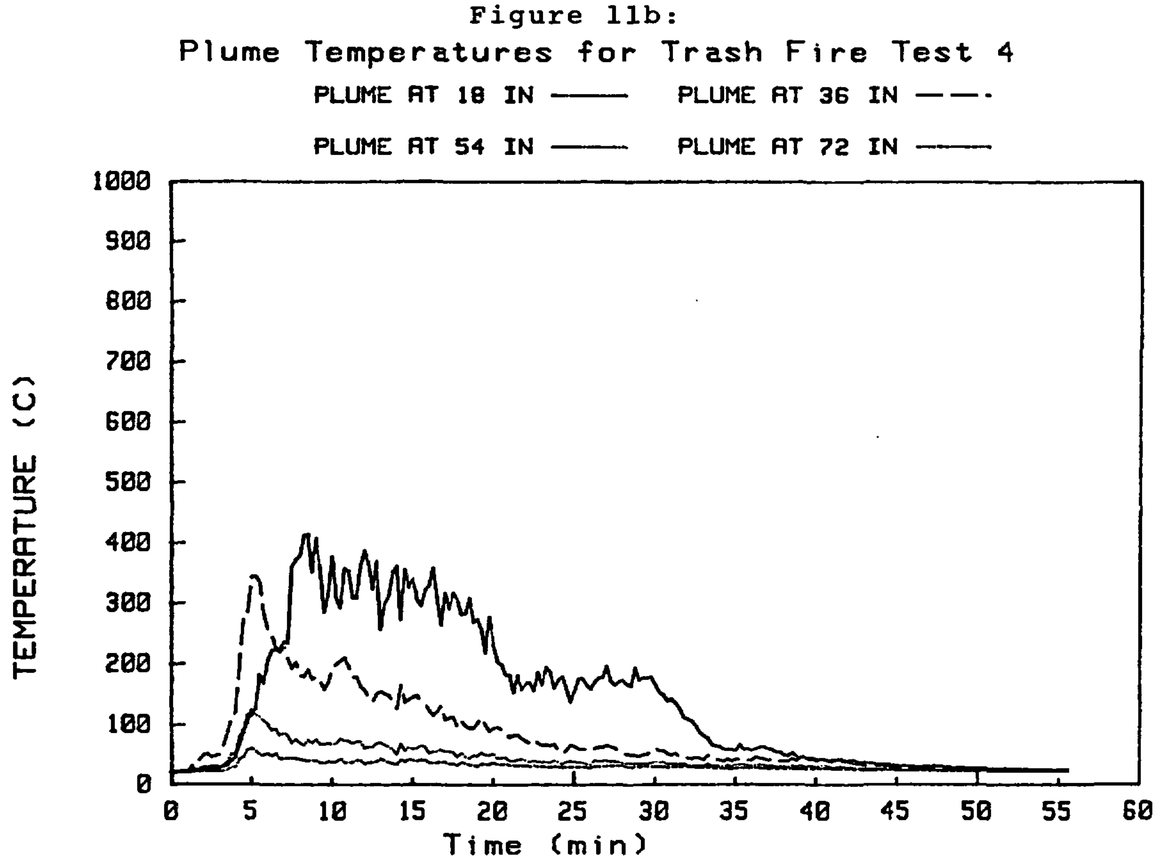


Figure 12a:
Fuel Mass for Trash Fire Test 3

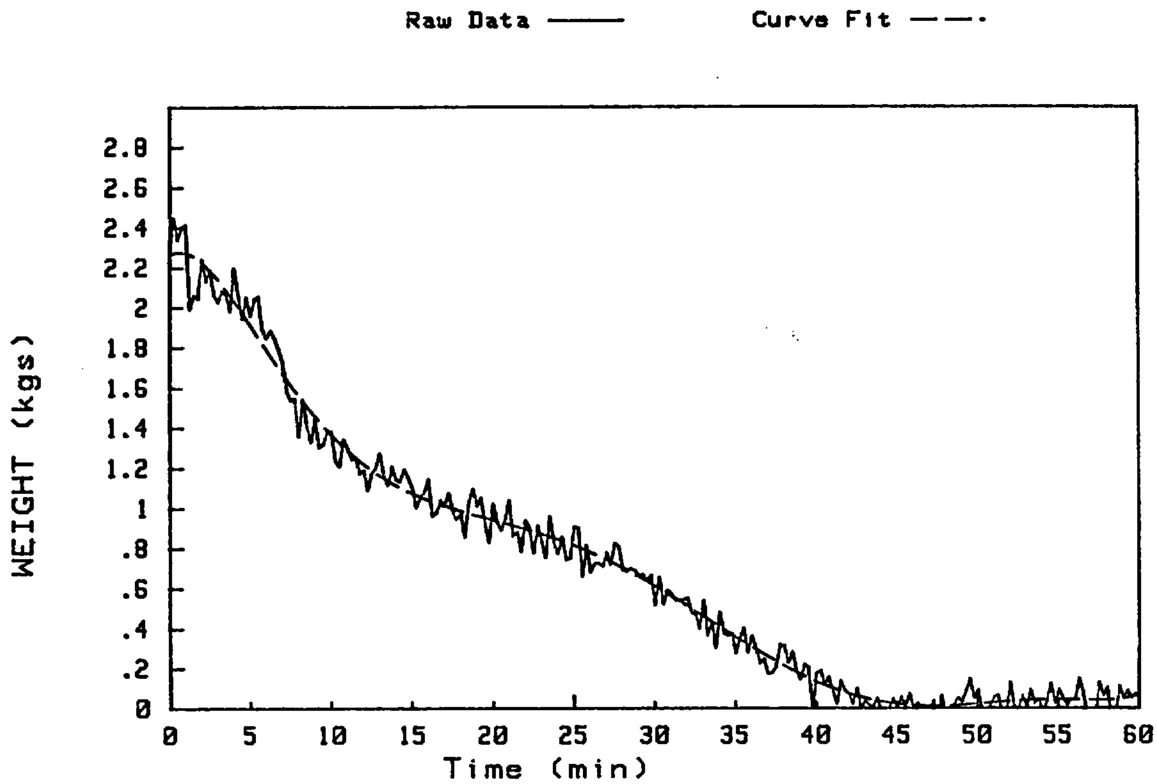


Figure 12b:
Fuel Mass for Trash Fire Test 4

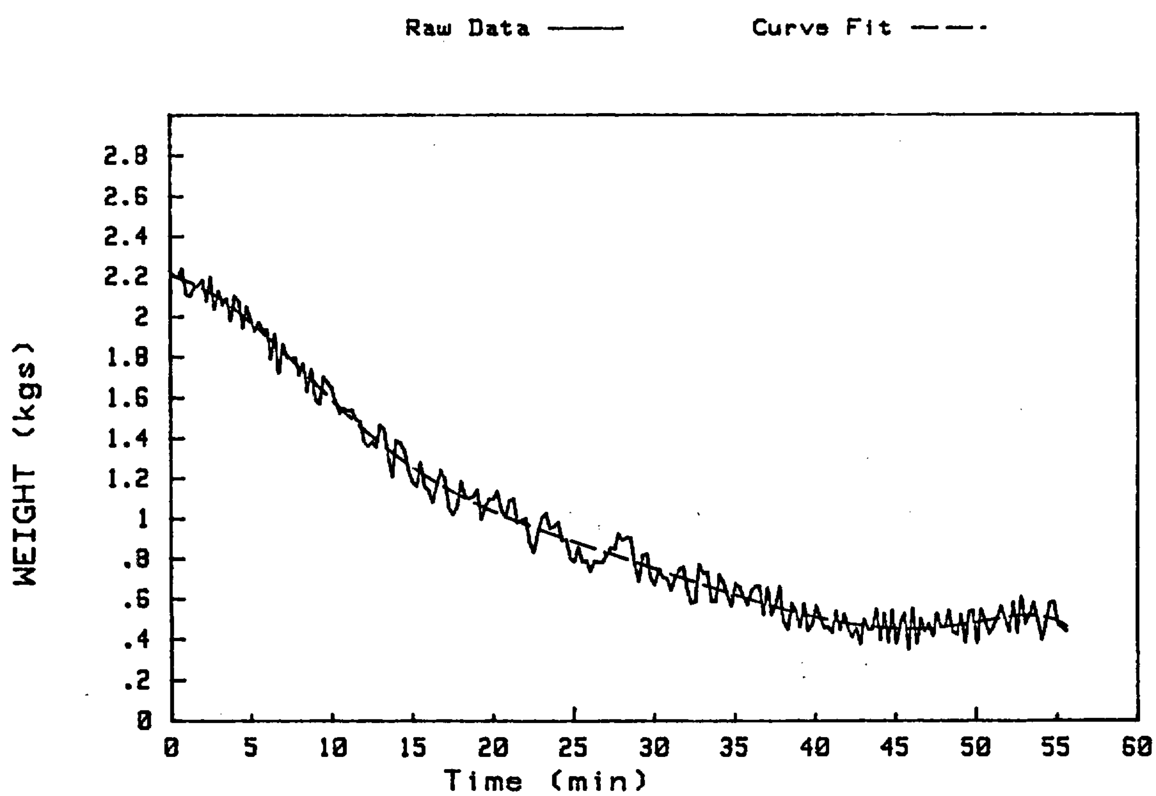


Figure 13a;
Fuel Mass Release Rate for Trash Fire Test 3

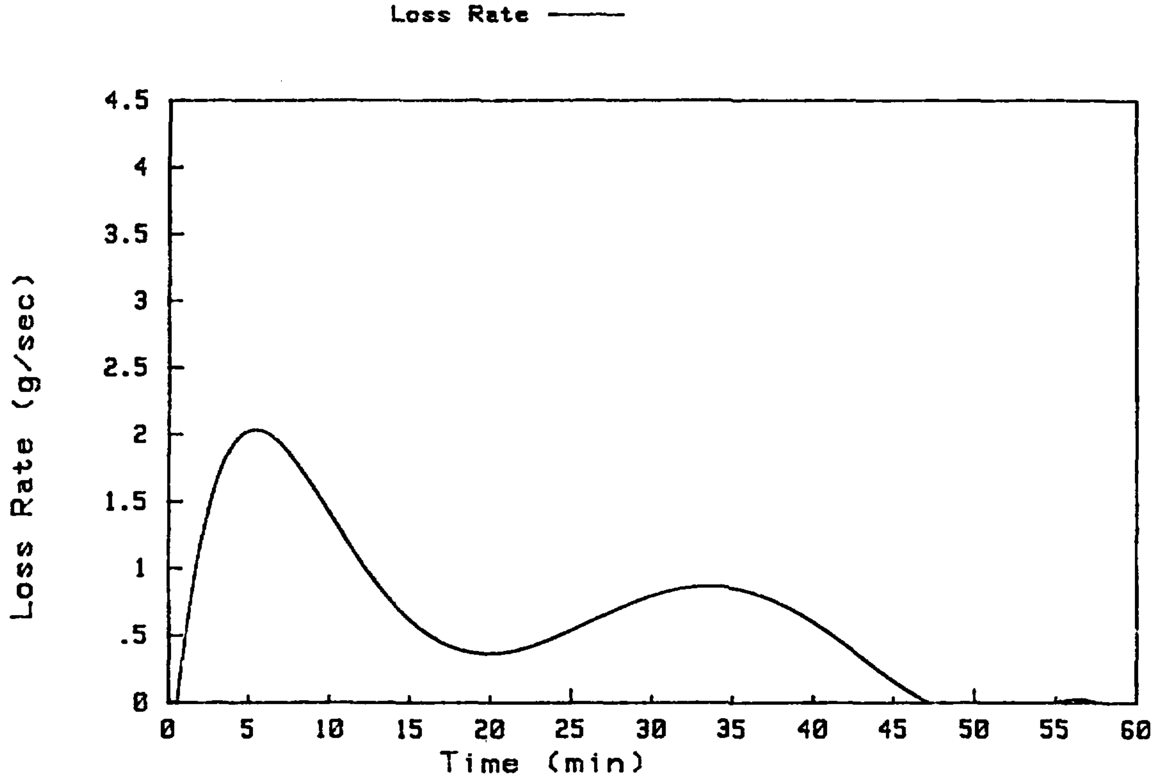


Figure 13b:
Fuel Mass Release Rate for Trash Fire Test 4

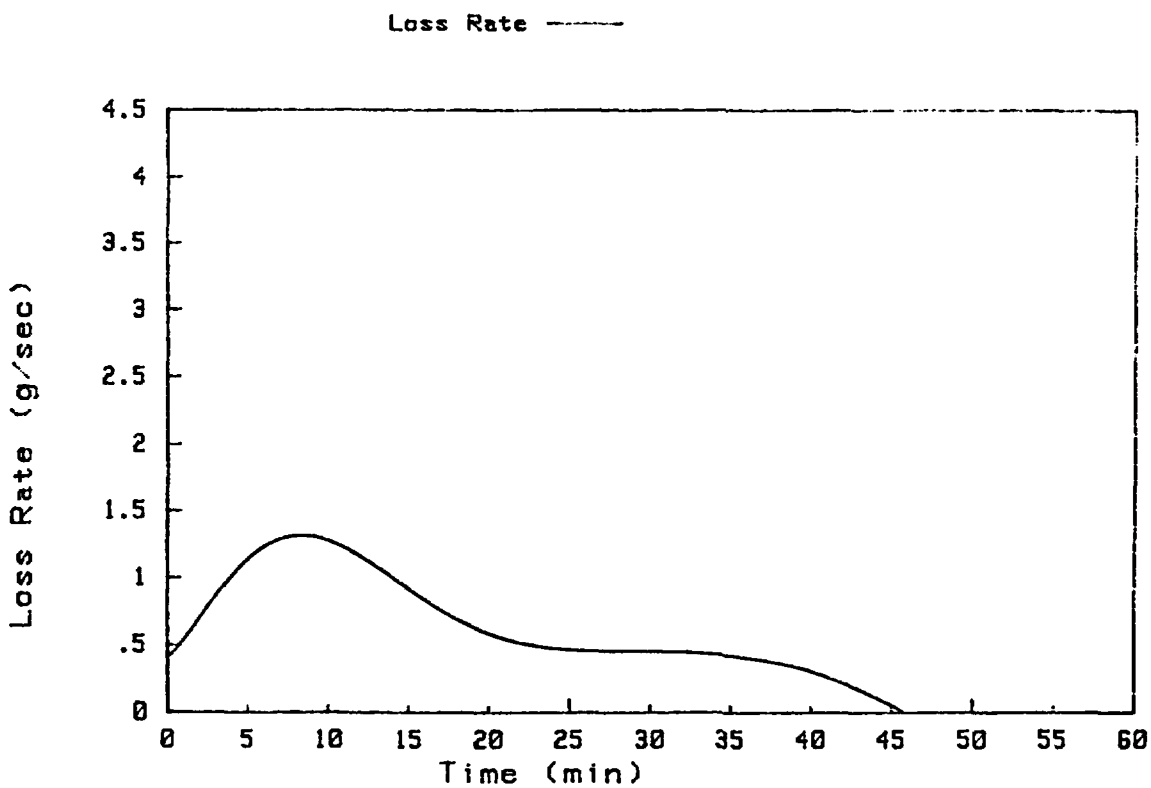


Figure 14a:
Heat Release Rate for Trash Fire Test 3

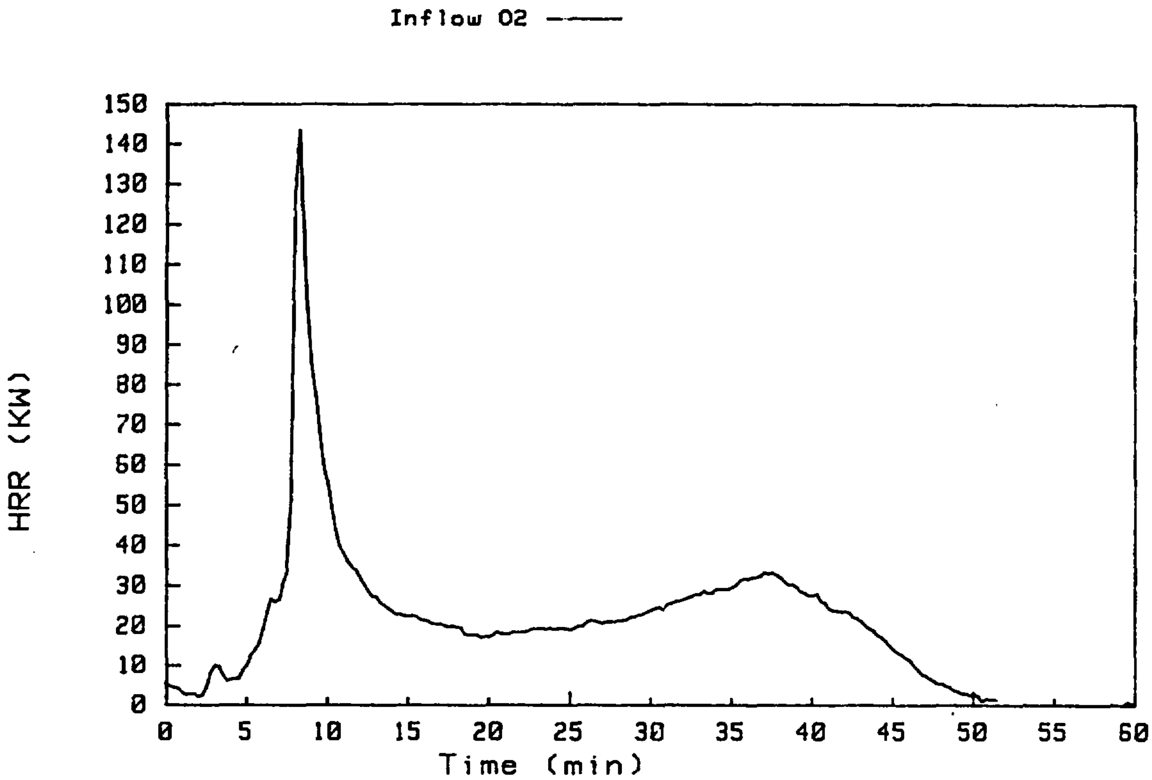
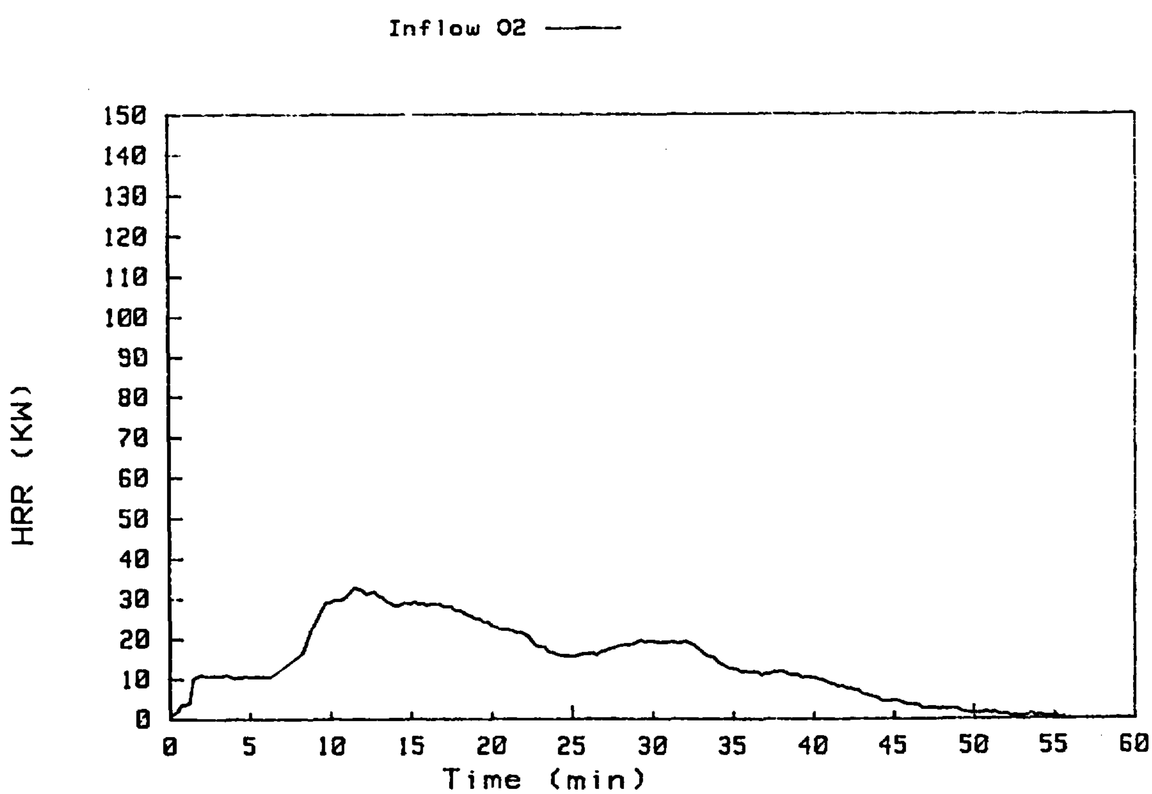


Figure 14b:
Heat Release Rate for Trash Fire Test 4



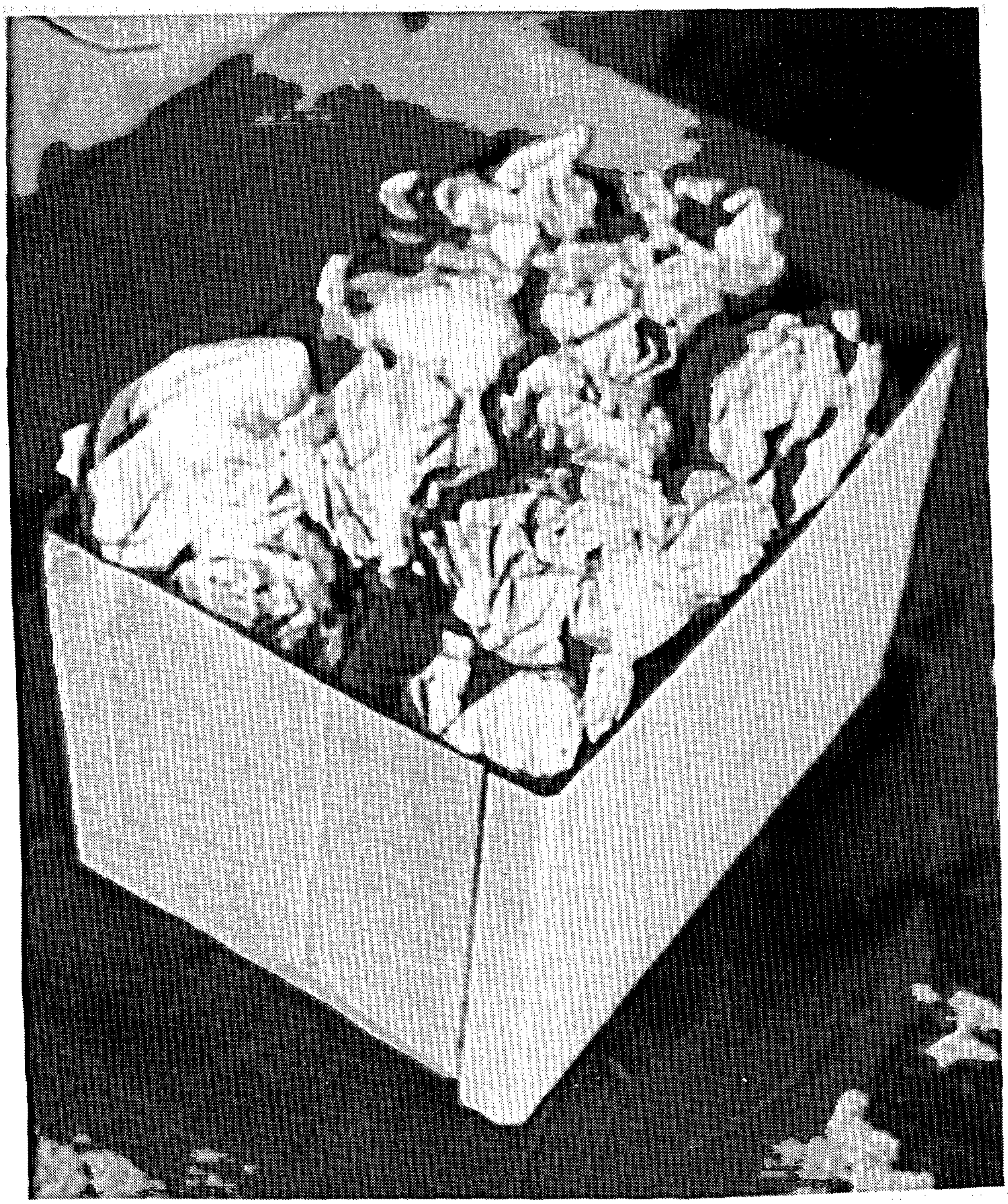


Figure 15 Photograph of FP3 Prior to Ignition

Figure 16 · Photograph of Post Test Residue from Test 5

Figure 17a:

Plume Temperatures for Trash Fire Test 5

PLUME AT 36 IN ——— PLUME AT 54 IN — — -

PLUME AT 72 IN ———

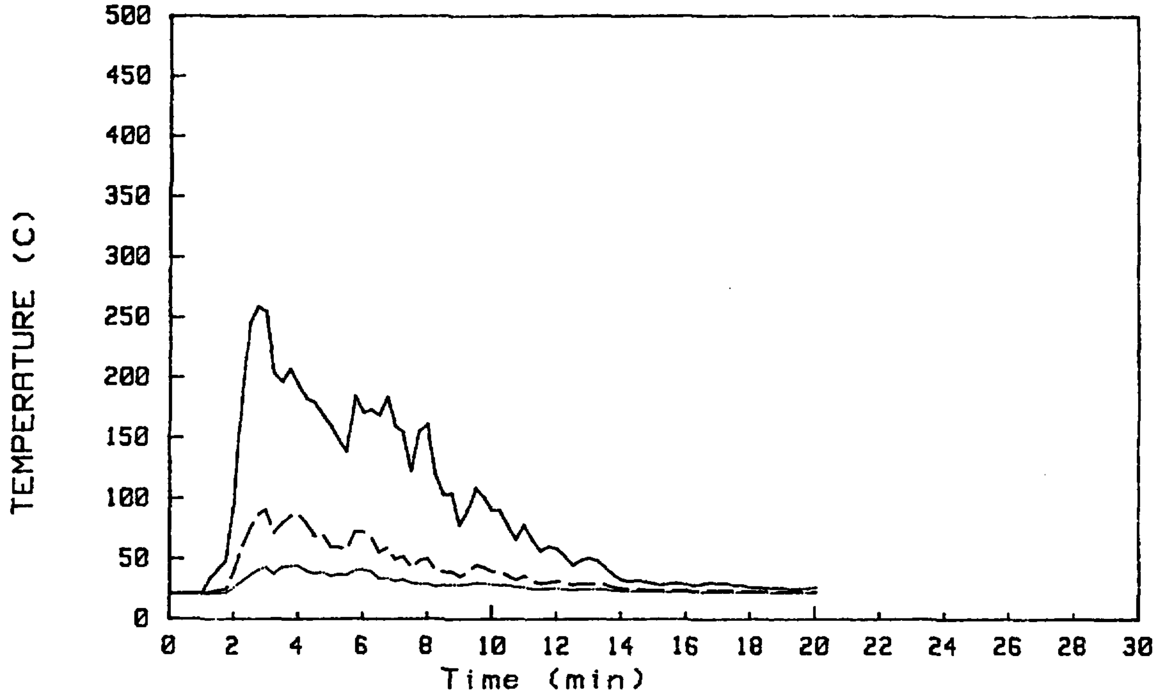


Figure 17b:

Plume Temperatures for Trash Fire Test 6

PLUME AT 36 IN ——— PLUME AT 54 IN — — -

PLUME AT 72 IN ———

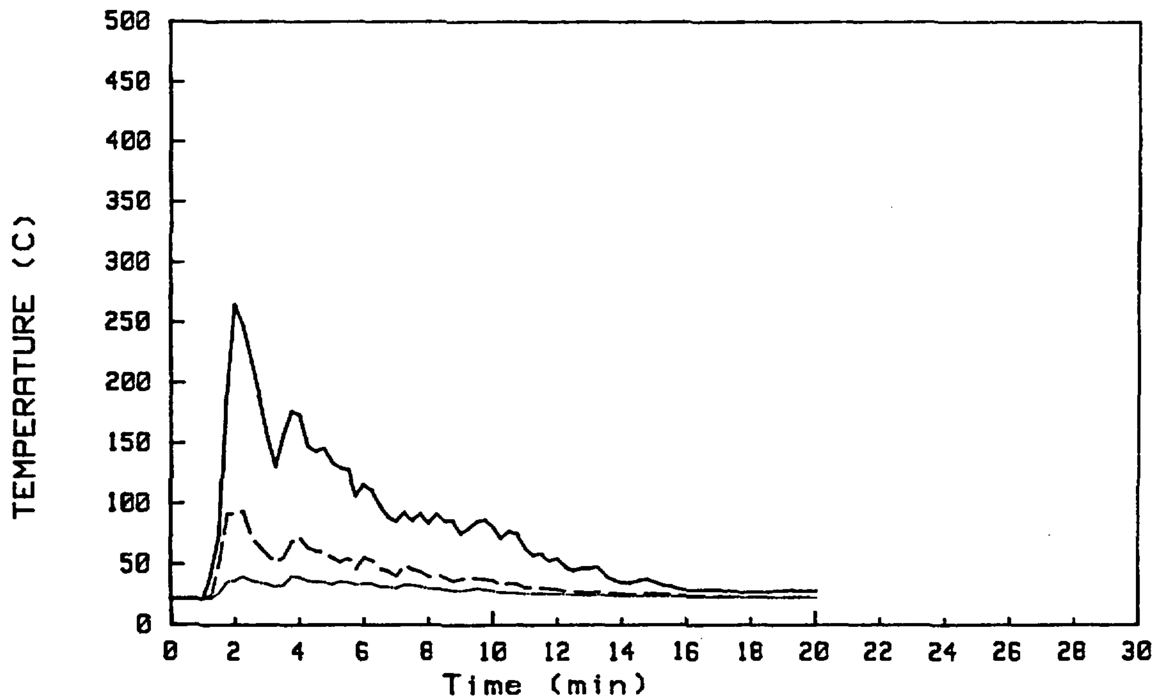


Figure 18a:
Fuel Mass for Trash Fire Test 5

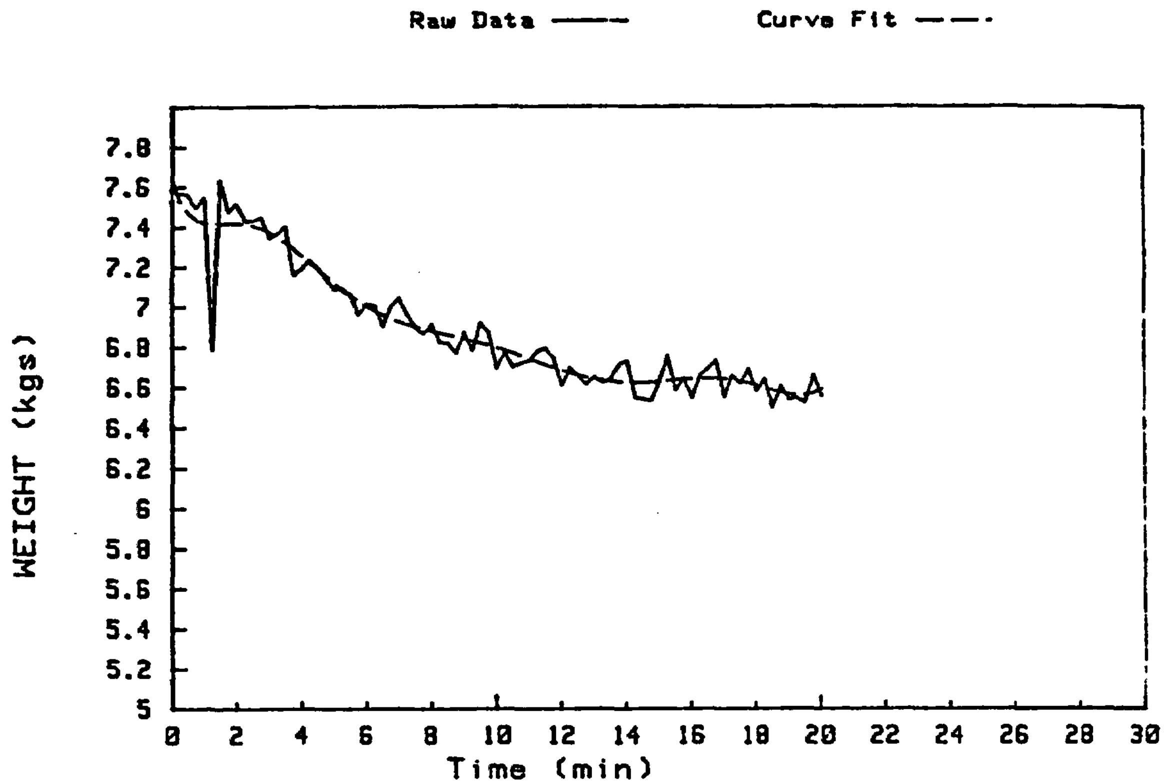


Figure 18b:
Fuel Mass for Trash Fire Test 6

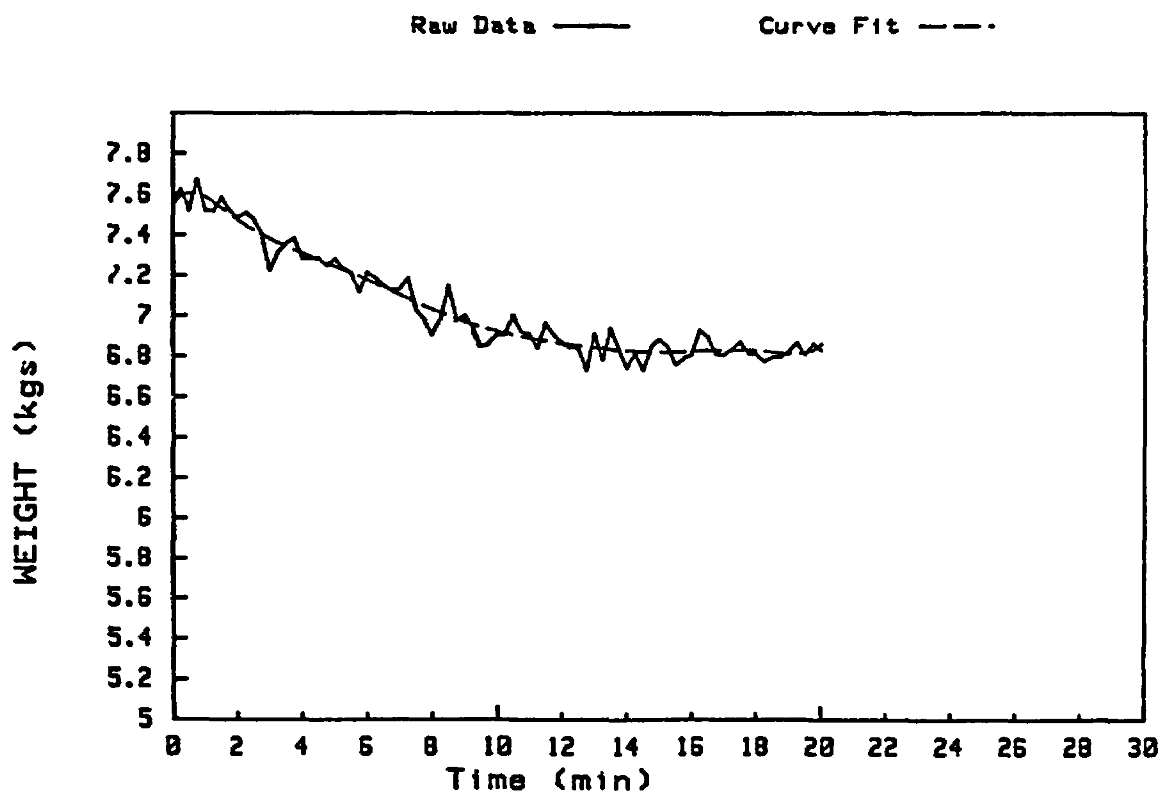


Figure 19a:
Fuel Mass Release Rate for Trash Fire Test 5
Loss Rate ———

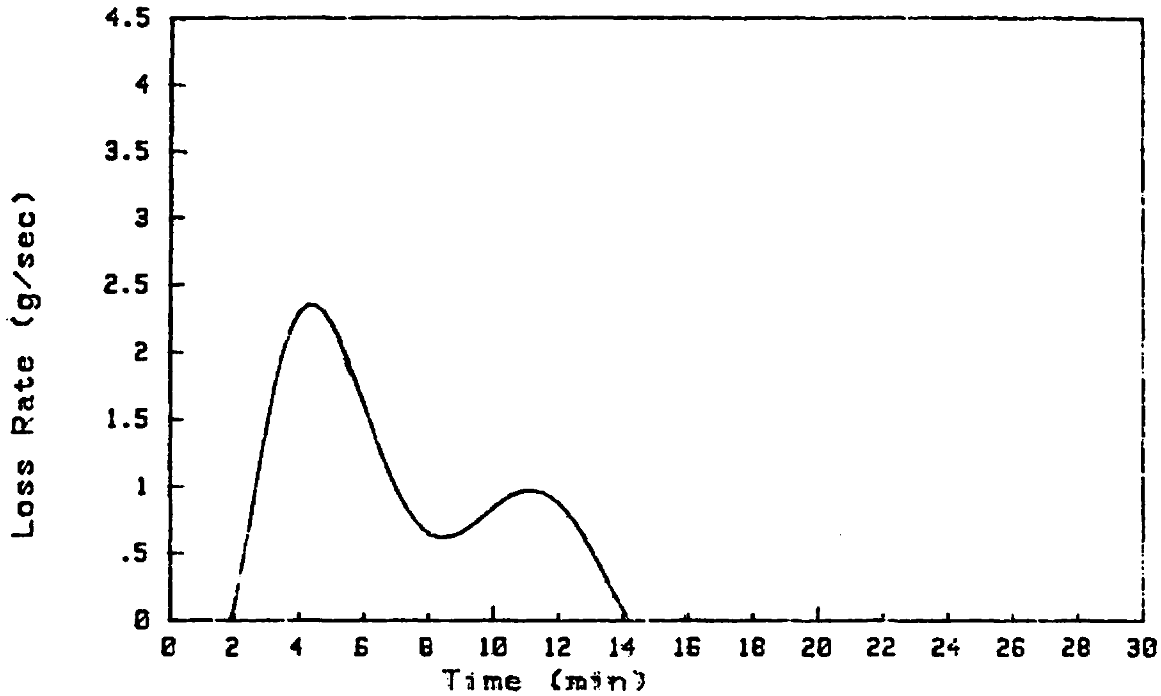


Figure 19b:
Fuel Mass Release Rate for Trash Fire Test 6
Loss Rate ———

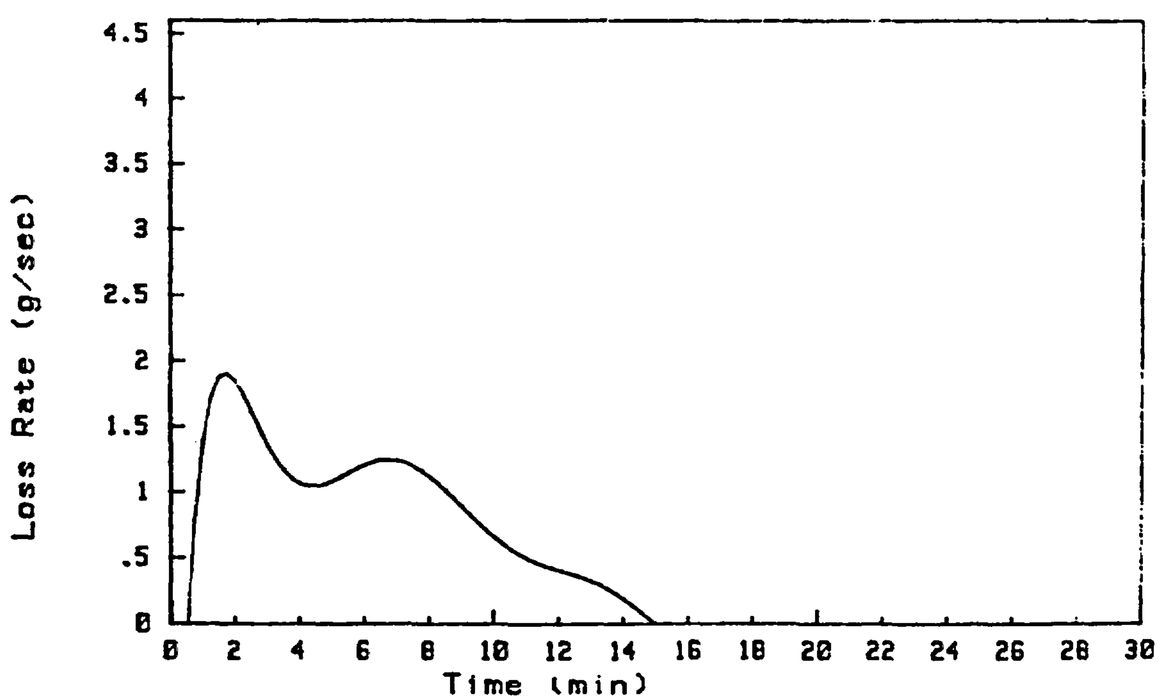


Figure 20a:
Heat Release Rate for Trash Fire Test 5

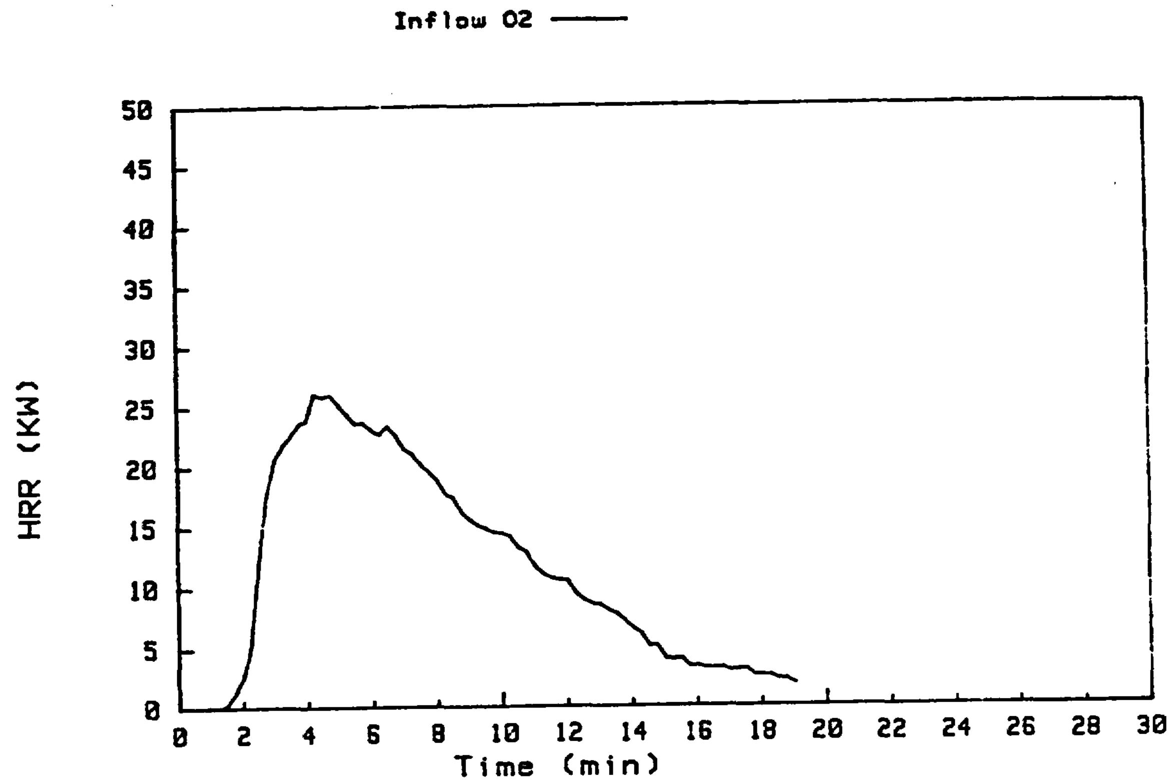
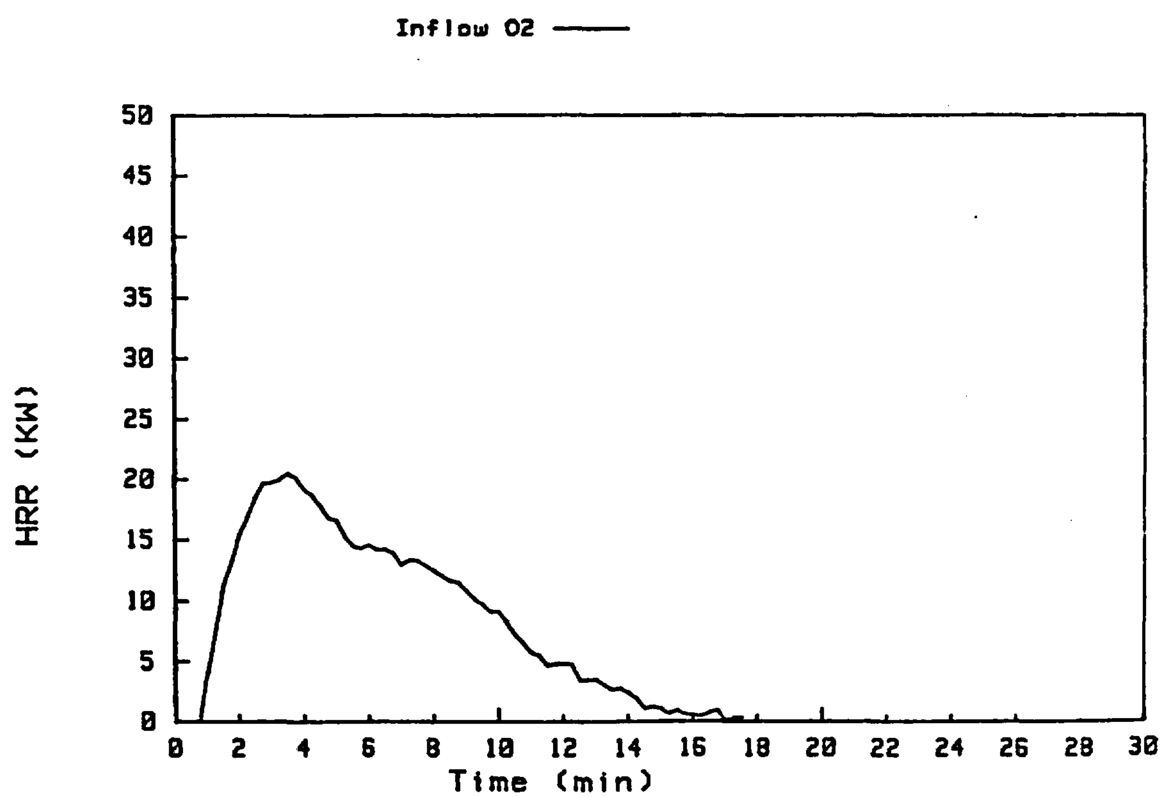


Figure 20b:
Heat Release Rate for Trash Fire Test 6



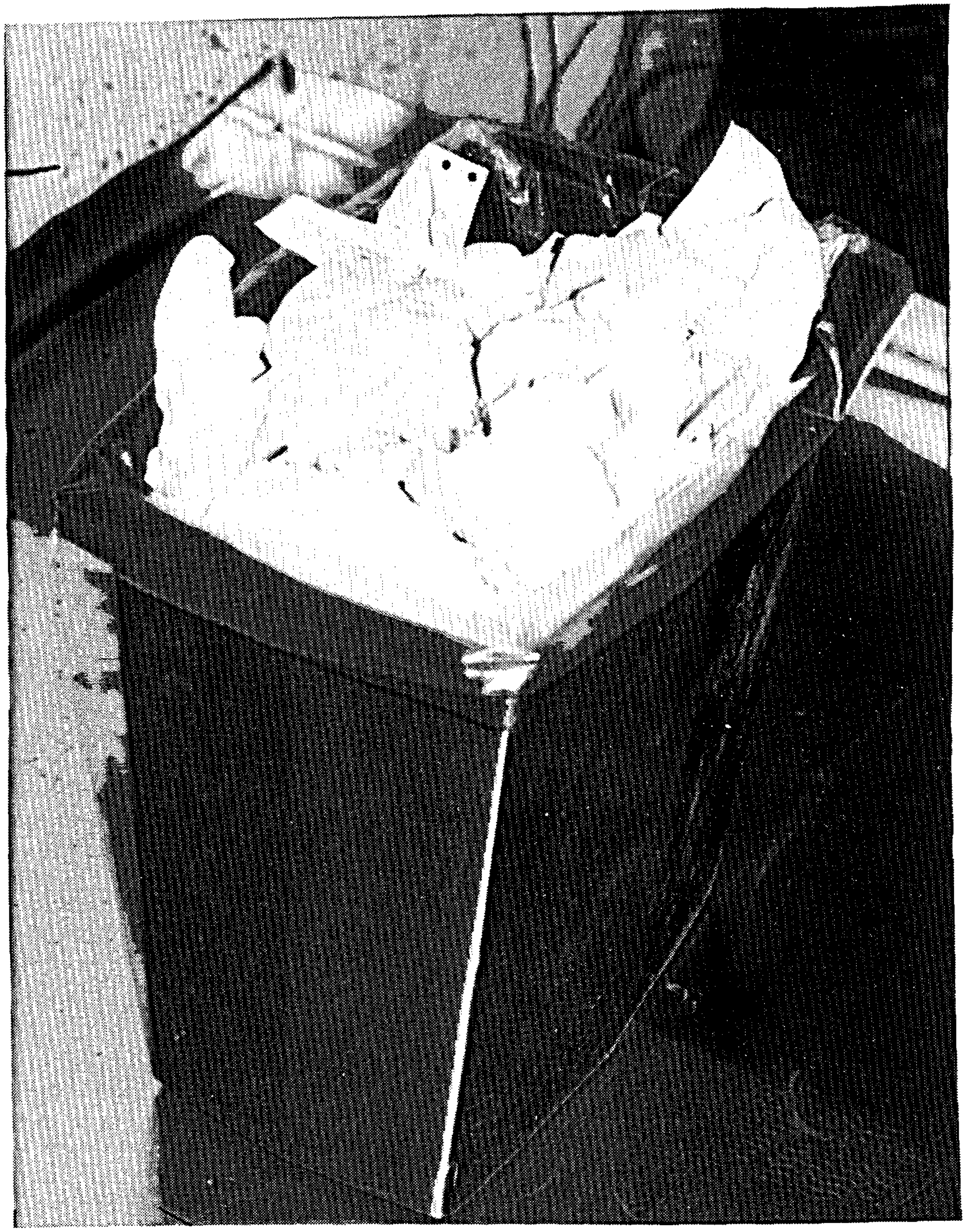


Figure 21 Photograph of FP4 Prior to Ignition

Figure 22a:
Plume Temperatures for Trash Fire Test 7

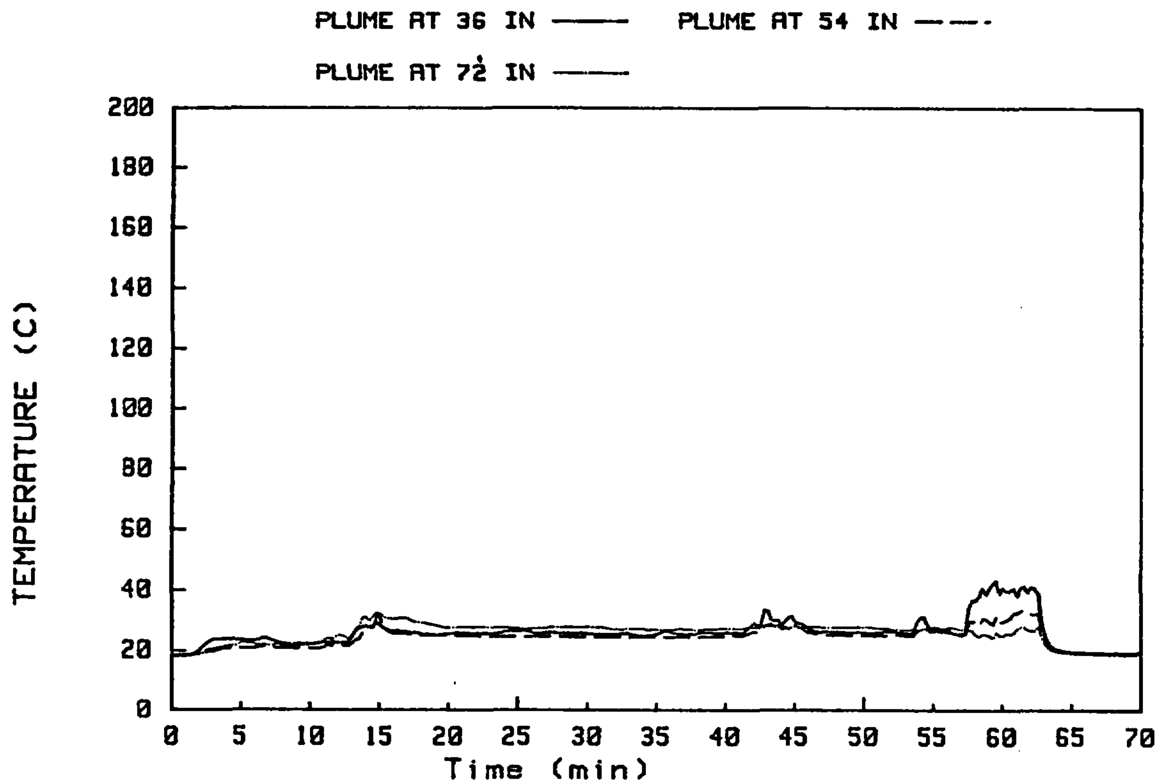


Figure 22b:
Plume Temperatures for Trash Fire Test 8

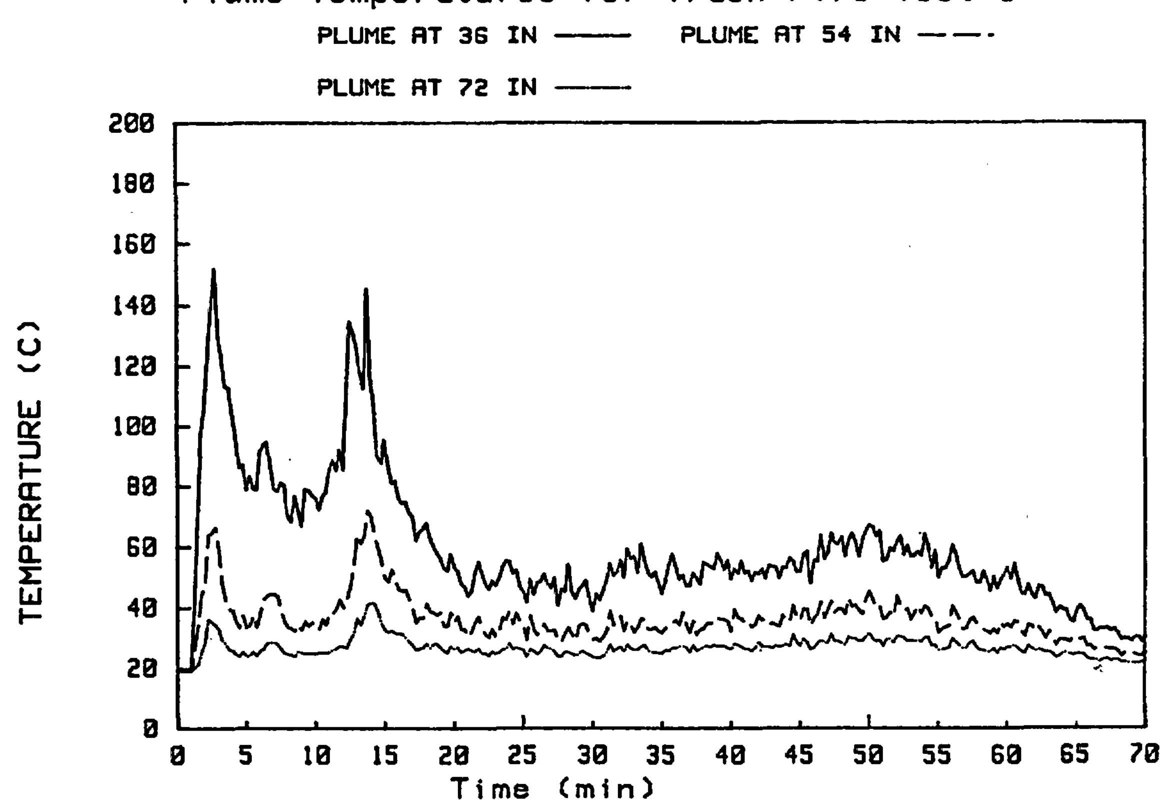


Figure 23a:
Fuel Mass for Trash Fire Test 7

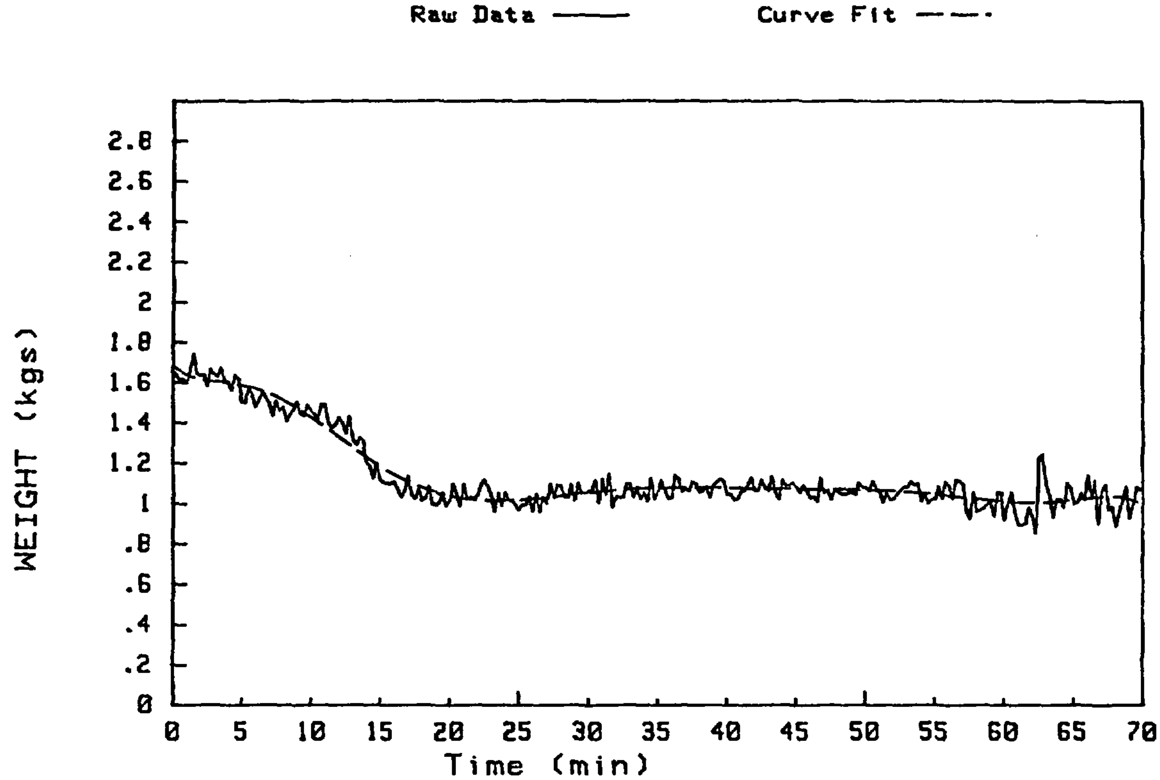


Figure 23b:
Fuel Mass for Trash Fire Test 8

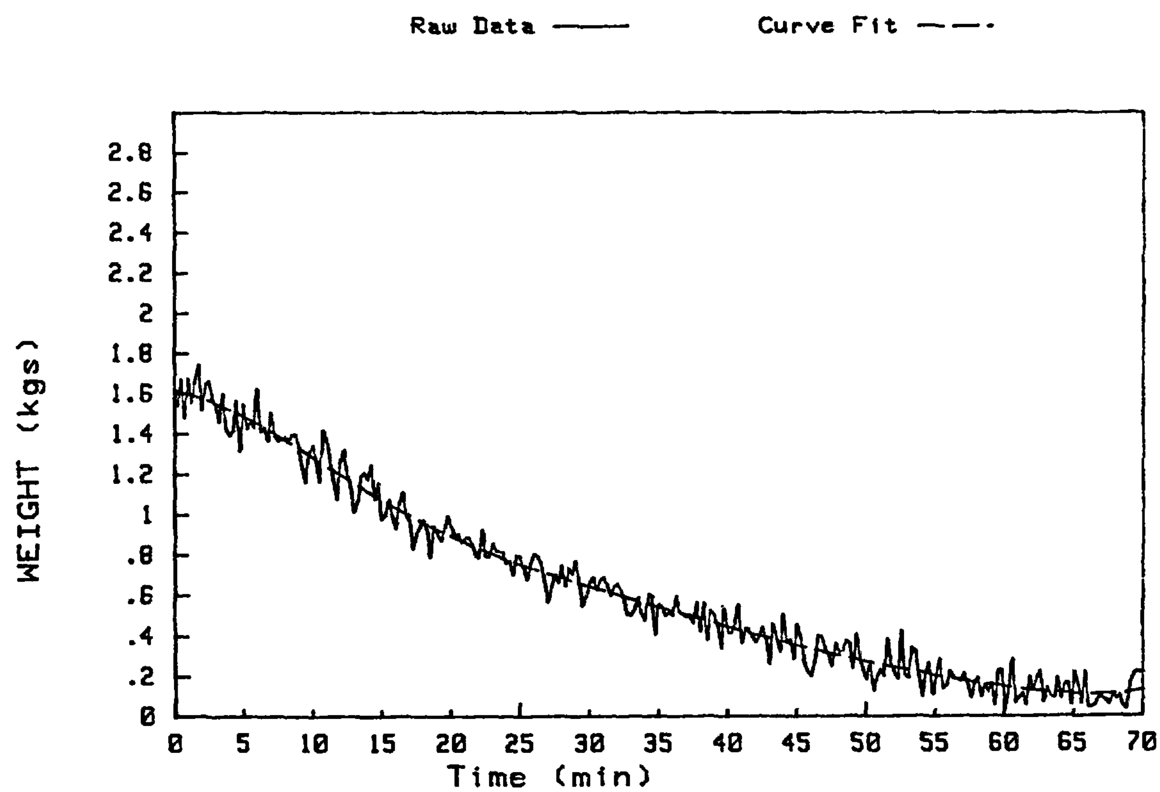


Figure 24a:
Fuel Mass Release Rate for Trash Fire Test 7

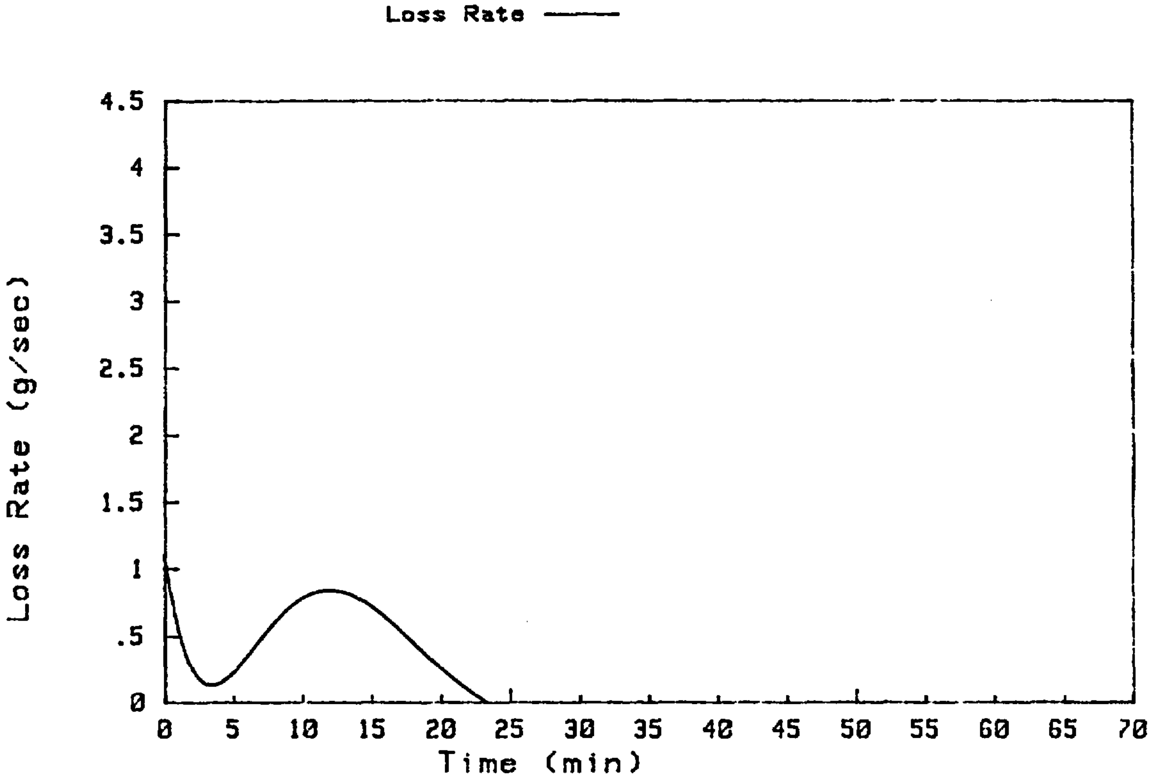


Figure 24b:
Fuel Mass Release Rate for Trash Fire Test 8

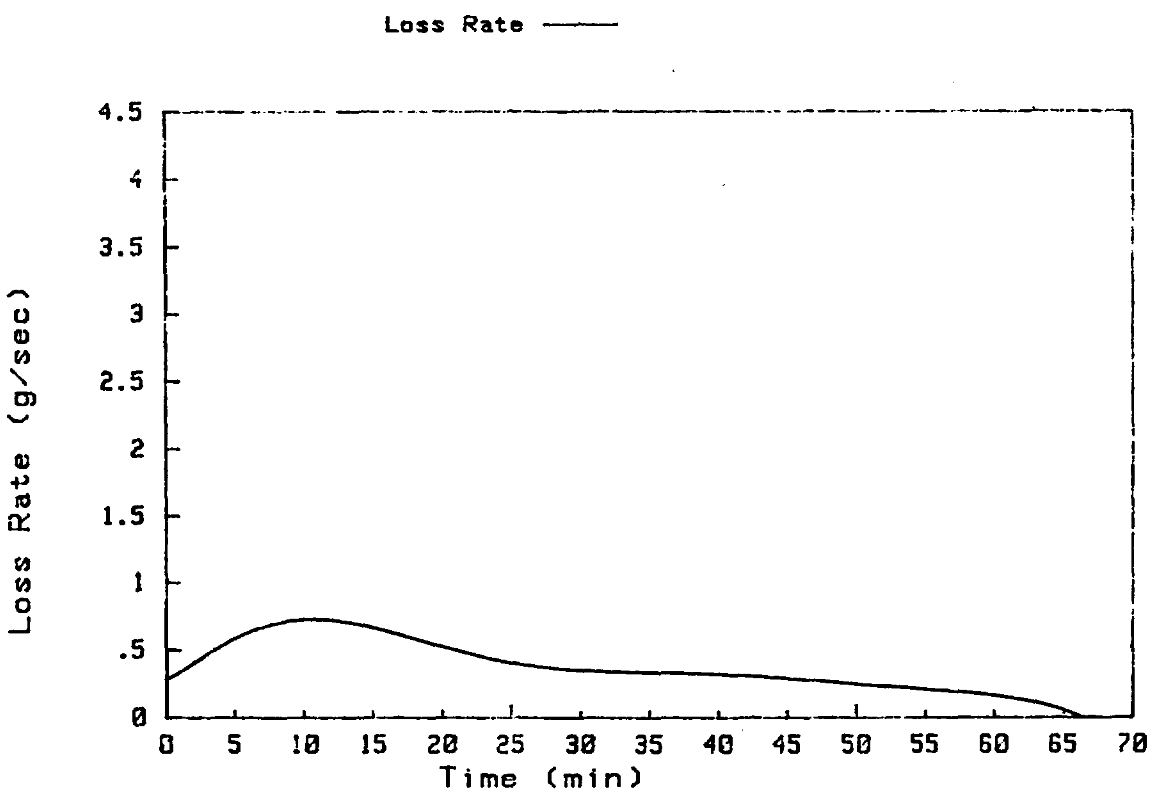


Figure 25a:
Heat Release Rate for Trash Fire Test 7

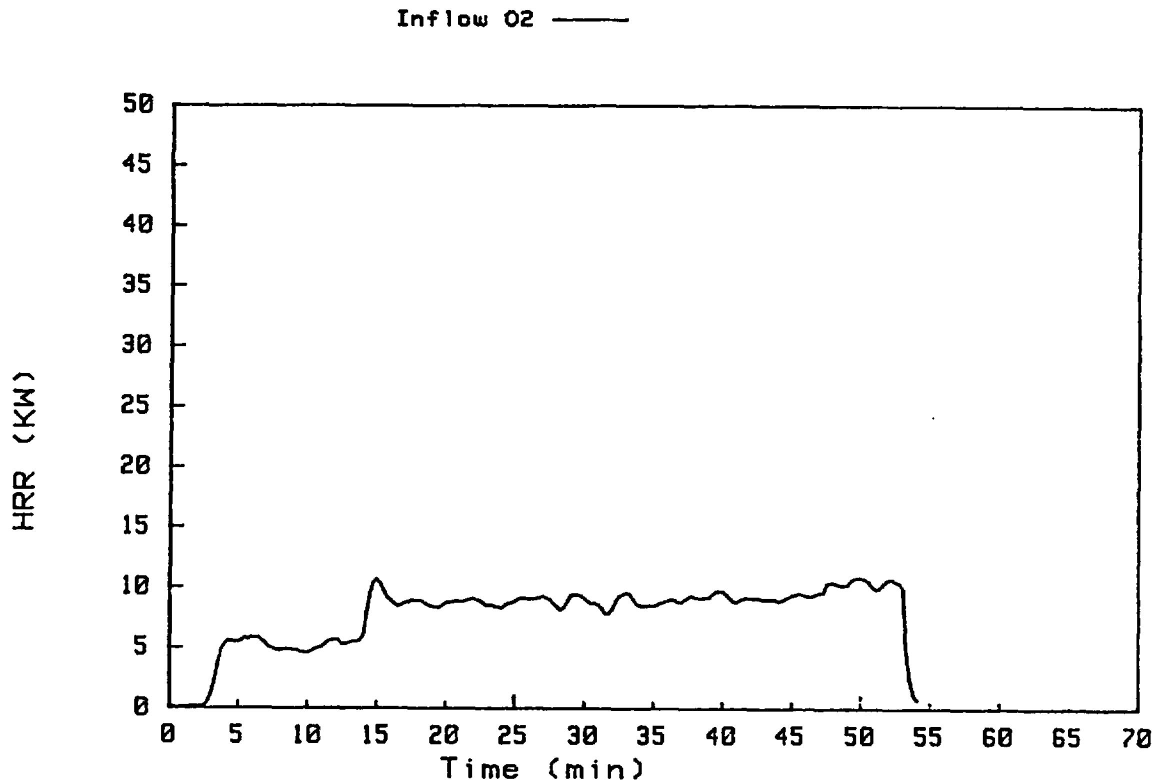
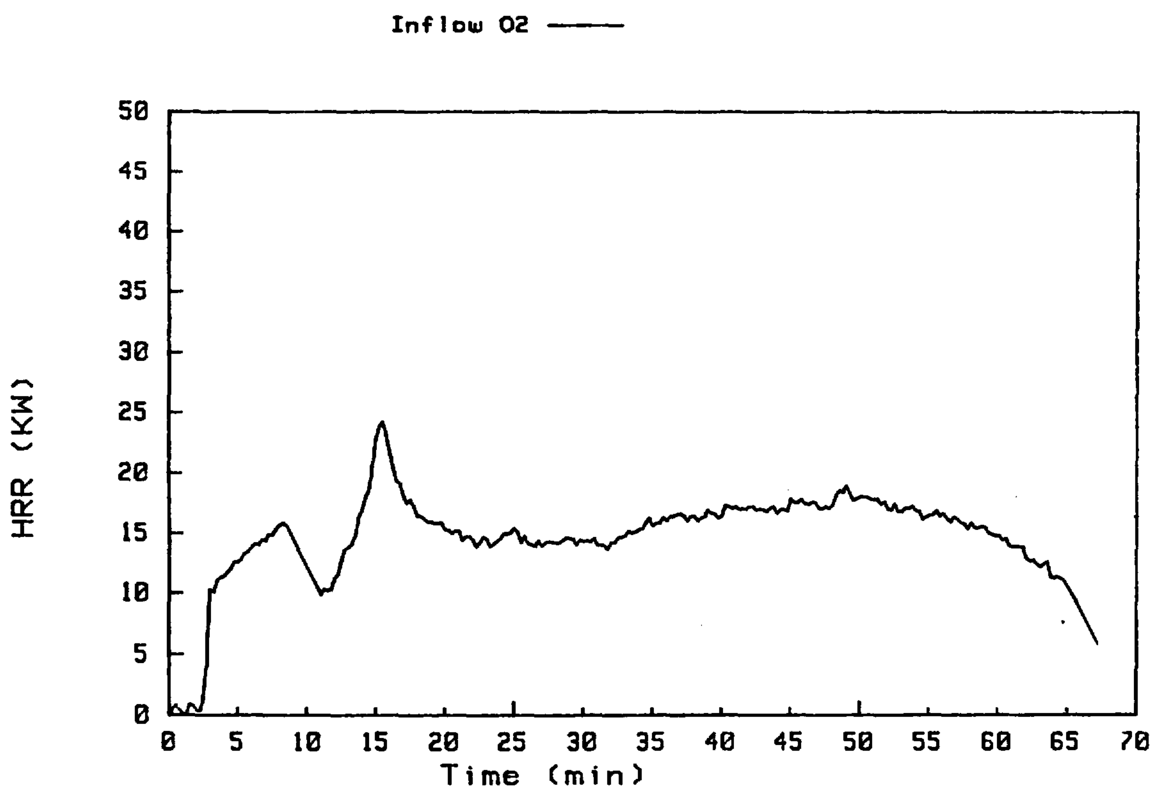


Figure 25b:
Heat Release Rate for Trash Fire Test 8



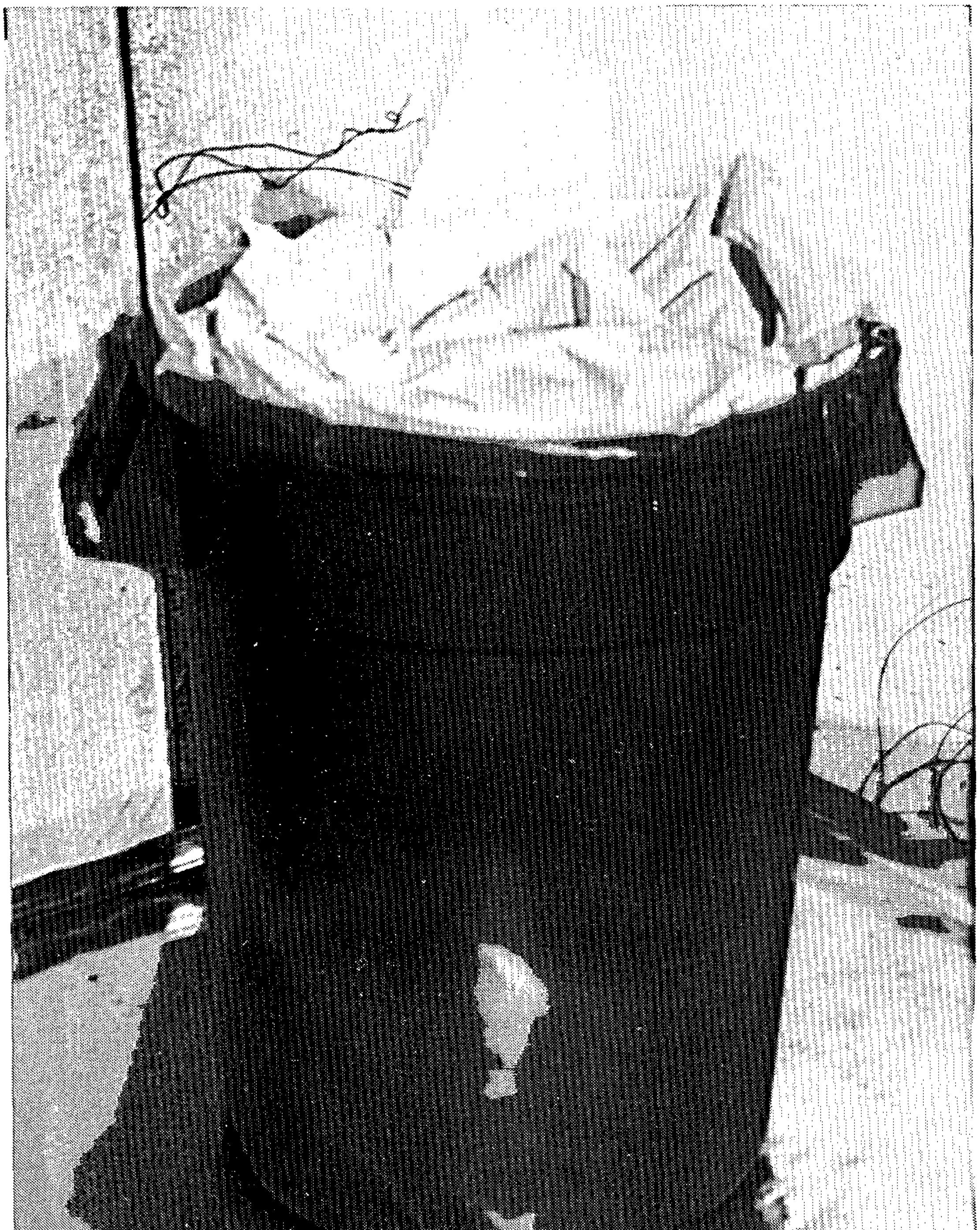


Figure 26 Photograph of FP5 Prior to Ignition

Figure 27 Photograph of FP5 at Time of Peak Intensity

Figure 28:
Plume Temperatures for Trash Fire Test 9

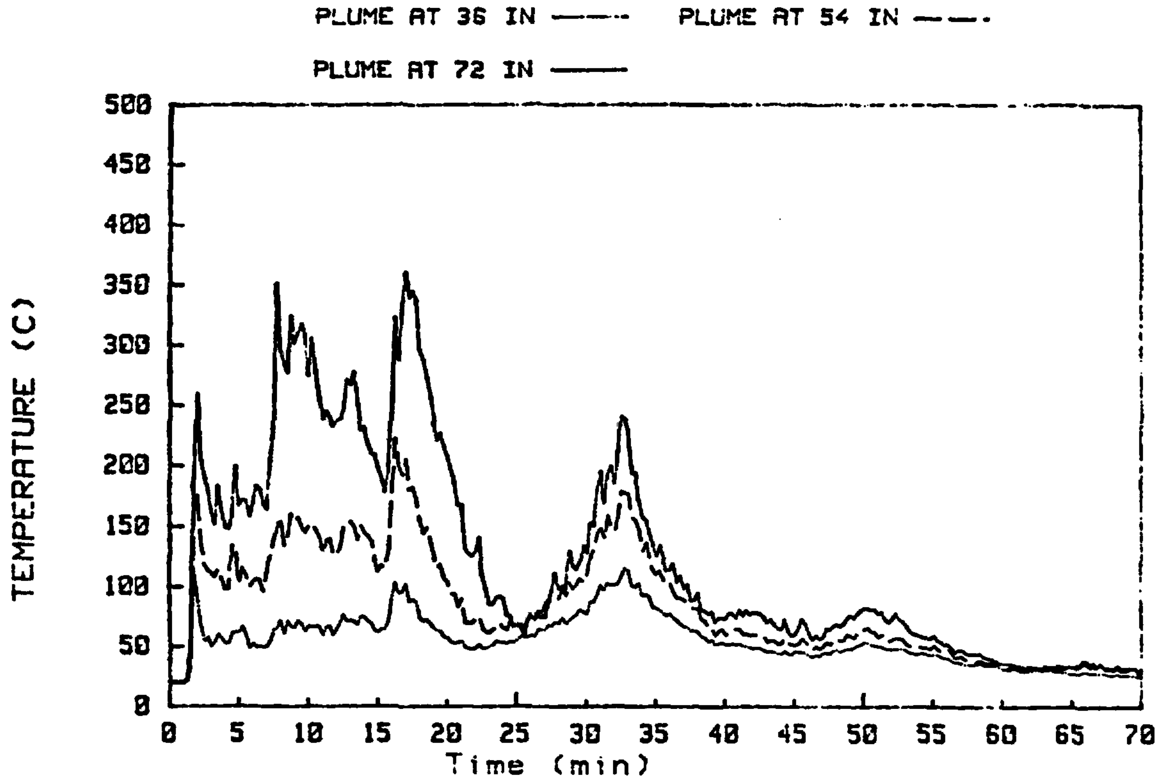


Figure 29:
Fuel Mass for Trash Fire Test 9

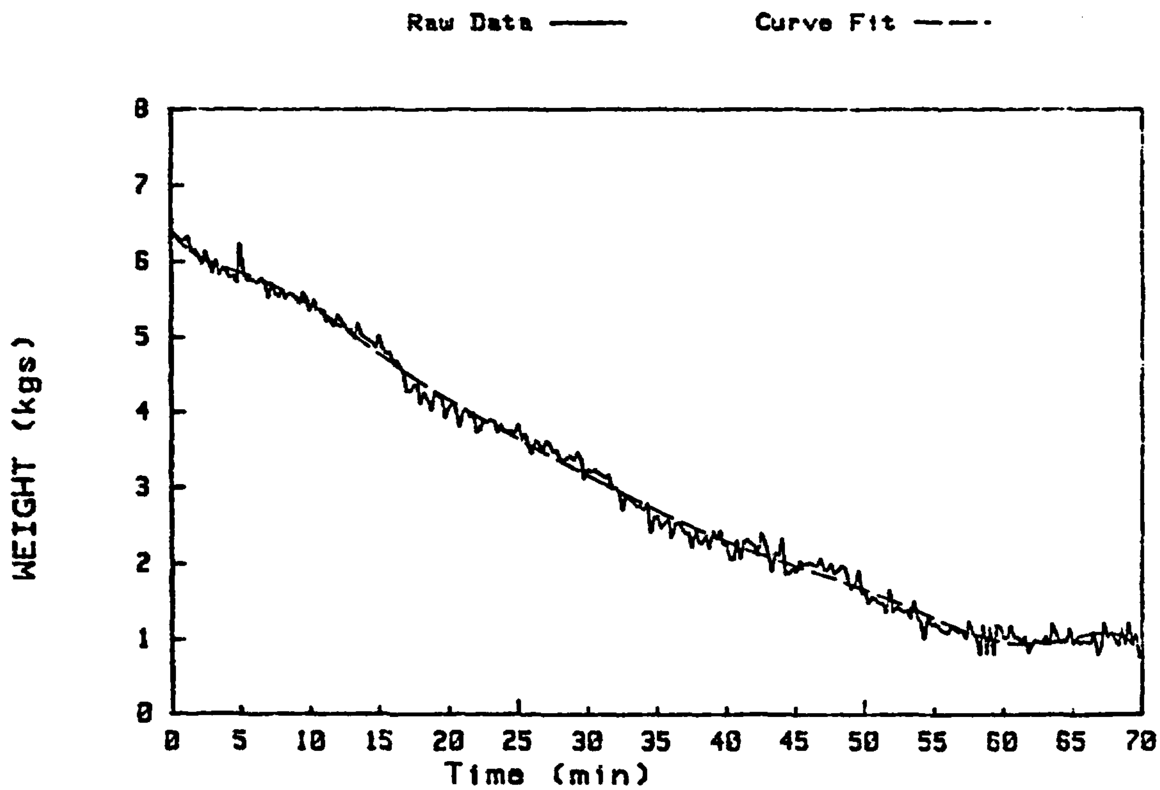


Figure 30:
Fuel Mass Release Rate for Trash Fire Test 9

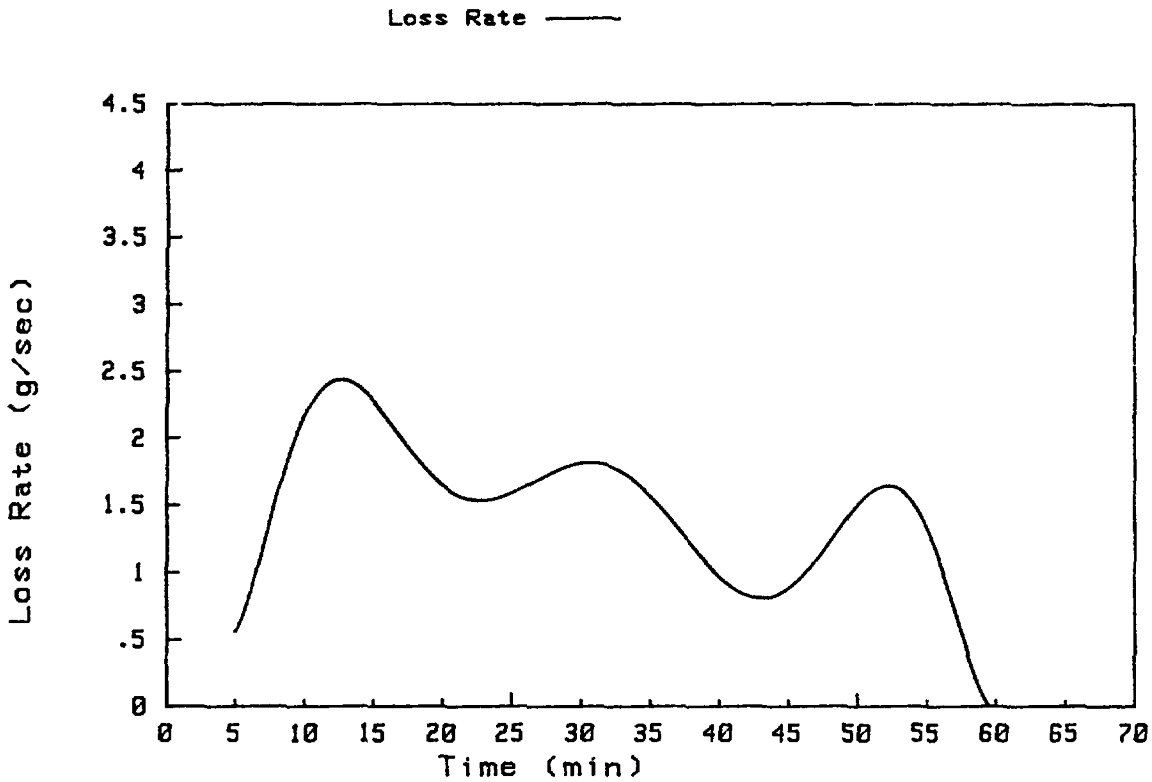
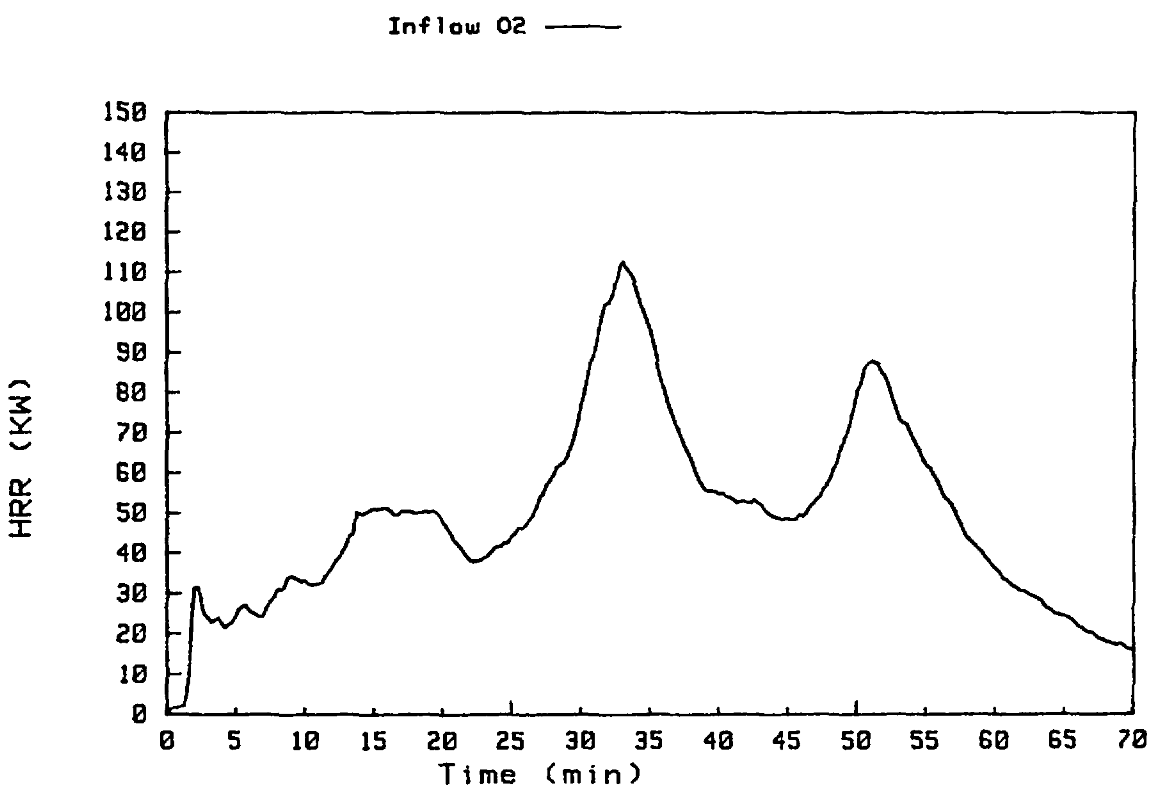


Figure 31:
Heat Release Rate for Trash Fire Test 9



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13. ABSTRACT (200 words or less)

Nine fire tests using five different trash fuel source packages were conducted by Sandia National Laboratories. This report presents the findings of these tests. Data reported includes heat and mass release rates, total heat and mass release, plume temperatures, and average fuel heat of combustion.

These tests were conducted as a part of the U.S. Nuclear Regulatory Commission sponsored fire safety research program. Data from these tests were intended for use in nuclear power plant probabilistic risk assessment fire analyses. The results were also used as input to a fire test program at Sandia investigating the vulnerability of electrical control cabinets to fire.

The fuel packages tested were chosen to be representative of small to moderately sized transient trash fuel sources of the type that would be found in a nuclear power plant. The highest fire intensity encountered during these tests was 145 kW. Plume temperatures did not exceed 820°C.

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